12

THE EFFECT OF LARGE EXTERNAL STORES ON THE LOW-SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A 60° SWEPT DELTA WING

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In Partial Fulfillment

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Master of Science in Aeronautical Engineering

By

Lee Treadwell Allen

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Approved:

Date Approved by Chairman: Feb. 24, 1955

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Doctor A. L. Ducoffe for his most generous aid, valuable criticisms, and guidance throughout the preparation of this thesis. Gratitude is extended to Doctor M. R. Carstens and Professor J. J. Harper for their review and criticism of the topic.

LIST OF SYMBOLS

C_D	drag coefficient (drag/qs)
C_L	lift coefficient (lift/qs)
C_M	pitching moment coefficient (pitching moment/MAC qs)
L/D	store fineness ratio (length/diameter)
MAC	wing mean aerodynamic chord, ft.
q	dynamic pressure ($\rho V^2 /2$), lbs./sq. ft.
RN_e	effective Reynolds number
S	wing area, sq. ft.
V	effective free stream velocity, ft./sec.
α	model angle of attack
η	wing spanwise station, tenths semi-span
ρ	mass density of air, slugs per. cubic ft.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

SUMMARY

In this report an experimental investigation was made to determine the effects of large external stores on the low-speed longitudinal aerodynamic characteristics of a 60° sweptback delta wing having NACA 0009 airfoil sections. The three parameters studied are store fineness ratio, store spanwise position, and a comparison of the effect of stores mounted on the upper and lower surfaces of the wing.

The purpose of this paper is to extend the limited data available for criteria in designing future interceptor type aircraft mounting large external stores.

The results obtained in this work show that from a lift standpoint the stores should be mounted on the upper surface of the wing as near the tip as possible. From the drag standpoint it was found that the stores should be mounted on the lower surface of the wing as near the tip as possible. If, however, the stores are mounted on the upper surface, they should be mounted as near the fuselage as possible. Fineness ratios in the range of 8 to 12 were found to have no appreciable effect on lift and drag. Static stability was found to increase with an increase in either fineness ratio or per cent semi-span position. All results correspond to an effective Reynolds number range of 2.45 to 3.97 million.

CHAPTER I

INTRODUCTION

With the development of the atomic and hydrogen bombs has come the development of higher-speed and longer-range aircraft to carry them. To defend against these, better defensive weapons such as the interceptor-type aircraft are being designed. The interceptor for instance will require a much higher fire power to make it almost certain that any attacking aircraft will be destroyed before it reaches its target.

It has already been realized that the ordinary types of armament employed in the second world war cannot fulfill these new requirements, and interceptors today are being designed to carry air-to-air rockets. Early types carried these rockets externally under the wings or fuselage but more recent designs carry them internally in pods mounted on the wings or in the fuselage itself. It is conceivable, however, that in the future these relatively small rockets may not give the interceptor the fire power it will require, especially if the development of bomber-type aircraft continues at the rate it has in the past few years. If this becomes the case, larger missiles or rockets must be employed. Increasing the size of the rockets will again make it necessary for them to be carried externally.

The effect of these larger missiles on the aerodynamic characteristics of the aircraft will be different from those of their smaller predecessors and new design criteria will be needed. It is the object of this investigation to determine some of these effects on the delta-type wing.

Many parameters related to the size, shape, and location of large external stores mounted on a delta wing could conveivably effect its aerodynamic characteristics. To investigate them all would be beyond the scope of this paper. For this reason, only three will be analyzed here. They are, the effect of store fineness ratio or length to diameter, the effect of store spanwise location, and a comparison of configurations having stores mounted on the top and the bottom of the wing. The investigation has also been confined to the low-speed-range effects of these parameters on lift, drag, and pitching moment.

The author has found that the amount of literature concerned with large external stores is very limited. For this reason in only a very few cases was it possible to make comparisons with other work.

CHAPTER II

APPARATUS AND MODELS

The experimental work in this project was conducted in the nine-foot-diameter wind tunnel at Georgia Tech. The tunnel is of the single-return type having a closed circular jet vented to the atmosphere. It is powered by a 200 horsepower synchronous motor driving a four-bladed variable-pitch propeller. Adjustment of the propeller pitch allows control of the wind velocity in the test section up to a maximum speed of 150 miles per hour. Forces and moments were measured by means of a six-component electro-mechanical balance system.

The model used in the present investigation was designed to permit tests of the wing alone and various wing-store combinations.

The basic wing was a 60 degree delta of 48 inch span, having an aspect ratio of 1.73 and an NACA 0009 profile in sections parallel to the plane of symmetry. The model was designed to be supported on a three-point strut system, the two forward struts being located on the two MAC quarter chord points. The location of the store mounting points as well as those for the strut supports are shown on the drawing of the basic wing in Fig. 1. The model was constructed of laminated mahogany with the exception of the wing tips which were made of aluminum.

The stores, or model rockets, used in the investigation were designed to allow a variation in fineness ratio (8, 10, and 12 being used) by merely changing the length of the center section which was made of three-inch outside-diameter aluminum tubing. The 37.5 inch radius ogive nose and the cylindrical tail section were made of solid mahogany, while the fins in the tail section were made of 1/8 inch aluminum sheet. Attached to the nose section was a straight pylon made of laminated walnut with a steel cap on the tip opposite the store. This pylon had an NACA 0009 airfoil section, was 4.5 inches in span (1.5 store diameters) and had a 7.6 inch chord. The leading edge of the pylon, when mounted on the wing, coincides with the wing leading edge at all span stations. All fairings between the wing and the pylons were made using plaster of paris. Details of the store assembly are shown in Fig. 2 and a photograph of the composite model in one configuration in Fig. 3.

CHAPTER III

PROCEDURE

A velocity survey was made in the test section of the nine-foot-diameter wind tunnel at Georgia Tech shortly before the experimental work on this project was begun. It was unnecessary, therefore, to repeat this work to obtain the information necessary for calculating desired manometer settings corresponding to mean indicated airspeeds of 121.4, 91.2, and 75.2 miles per hour over the model. These speeds correspond to effective Reynolds numbers of approximately 3.97, 3.13, and 2.45 million respectively.

It was also unnecessary to make any tunnel tests to determine the tare and interference effects caused by the model mounting system since these effects had been evaluated in a test program immediately preceeding this one in which the identical model was tested at an indicated airspeed of 120 miles per hour.

The wind-tunnel tests made during this investigation were conducted in a manner which allowed the effects of the involved parameters on the longitudinal aerodynamic characteristics of the wing to be determined independently of each other. These parameters are store fineness ratio, store spanwise position, and a comparison of the effect of stores mounted on the upper and lower surfaces of the wing. It should be noted here that these are not the only parameters involved but merely the ones to be analyzed in this report.

The model, operating at a mean indicated airspeed of 121.4 miles per hour, was tested in ten configurations, the first being the wing alone. In the other nine configurations two stores, both with fineness ratios of 8, 10, or 12, were mounted symmetrically on the wing at one of the three spanwise stations used. These were 60, 40, and 22 per cent semi-span respectively. The inboard station at 22 per cent semi-span was dictated by the size of the fuselage which is to be used in a future test program to estimate fuselage effects. The selection of 60 per cent semi-span as the extreme outboard station can be considered as intuitive. It is reasoned that the weight of these air-to-air rockets would restrict their outboard position purely from a structural point of view. However, it is realized that large increases in lift and significant reductions in drag have been realized with tip mounted fuel tanks. The stores were always mounted on the top of the wing in order to eliminate interference effects between the stores and the three-point-support mounting system. Since the wing is symmetrical (0009 airfoil section), data taken at positive angles of attack simulates stores mounted on the upper surface whereas negative angles of attack correspond to stores mounted on the lower surface.

In all configurations the model was tested at angles of attack ranging from -24 to +24 degrees in three degree increments. The lift and drag were recorded at each angle of attack, while the pitching moment was only read at angles ranging from +6 to -24 degrees. No investigation was made of the pitching moments associated with the model having stores mounted on the upper surface of the wing.

Tunnel runs were also made at airspeeds of 91.2 and 75.2 miles per hour on the wing alone and on the wing with the medium length store

(L/D = 10) mounted at the inboard station (η = 22 per cent). These runs were made to evaluate any Reynolds number effects which might be present.

Tunnel alignment corrections were obtained from the data recorded during the tests on the wing alone after gravity, tare and interference, and tunnel wall corrections had been made. The model was never actually inverted, but since it is symmetrical (NACA 0009) it was felt that this was not necessary.

The accuracy of the balance system has been found to be well within the accepted limits of one-tenth of one per cent of applied load except for very small loads, Ref. (1). Here accuracy is limited by beam sensitivity which is approximately as follows:

Lift . . . . 0.10 lb.

Drag . . . . 0.05 lb.

Pitching Moment . . . . 0.20 ft.-lb.

It should be kept in mind that the errors present in the reduced data could be twice as large as those mentioned above since the errors in both wind on and wind off readings are involved.

CHAPTER IV

RESULTS

The results of this investigation are shown in Figs. 4 through 26. To simplify the discussion, these figures will be divided into four groups, Figs. 4 through 10 being concerned with lift, 11 through 17 with drag, 18 through 21 with pitching moment, and 22 through 25 with the effect of Reynolds number on lift and drag.

Lift.--The lift curves are presented in Figs. 4 through 9. Several observations were made during a study of these curves, the most notable being the effect of store spanwise location on lift curve slope. At zero lift, a movement of the store outboard along the span is accompanied by a linear increase in the slope of the lift curve. This effect is shown in Fig. 10 as a plot of $dC_L/d\alpha$ versus store spanwise position for the zero lift condition. At a lift coefficient of approximately three-tenths, this effect disappears and all lift curve slopes, regardless of the store spanwise position, approximate the slope of the lift curve for the wing alone. This condition exists up to a lift coefficient of about seven-tenths for the model with stores mounted on either the top or the bottom of the wing. In Figs. 4 through 6 (simulating the wing with stores on the upper surface) it is noted that the lift curve falls off quite rapidly above $C_L = 0.7$ for the $\eta = 0.60$ semi-span station, whereas in Figs. 7 through 9 (simulating the wing with stores on the lower surface) above a lift coefficient of seven-tenths the lift curve slopes fall off for $\eta = 0.40$ for all L/D tested and for $\eta = 0.60$ for L/D = 8 and L/D = 10. Except as just mentioned, the store fineness ratio does not appreciably change the lift curve slope.

No uniform effect on angle of zero lift, traceable either to spanwise location or fineness ratio of the stores could be found. The wing with stores mounted on the top showed a decrease in angle of zero lift of from one to three-tenths of a degree, while the wing with stores mounted on the bottom showed an opposite effect as would be expected.

No observations on the effect of store location on $C_{L_{max}}$ could be made since the clearance between the model and the rear support would not allow the model to be operated at angles of attack in excess of twenty-five degrees.

<u>Drag</u>.--The drag polar diagrams are presented in Figs. 11 through 16. From these curves, plots of ΔC_D (due to stores) versus lift coefficient were made with store spanwise location as a parameter (Fig. 17). Only data for L/D = 12 is presented since the effect of L/D on ΔC_D was negligible. Two sets of curves, corresponding to upper and lower surface store mounting, are shown.

From Fig. 17 it can be seen that the efficiency, from the point of view of drag, of the model with stores mounted below the wing increases as the store position is moved progressively outboard, indicating that the $\eta = 0.60$ station is the most desirable and $\eta = 0.22$ the most undesirable. This holds true up to a lift coefficient of approximately six-tenths. Above this point the data indicates no uniform effect of store spanwise location on drag. It can also be seen that up to a lift coefficient of about five-tenths the drag due to the stores at all span stations decreases with increasing C_L. Beyond this point the drag starts to increase.

For the model with stores mounted above the wing, quite different results are obtained. Up to a lift coefficient of approximately three-tenths the outboard store position remains the most efficient and the most inboard, the least efficient. At about this point however, the drag due to the store mounted at the inboard position becomes less than that due to the stores mounted at the outboard positions, indicating that above $C_L = 0.3$ the $\eta = 0.22$ station is the most desirable while the $\eta = 0.40$ station is the least desirable. This is probably a result of the spanwise flow over the outer portions of the wing causing the pylons mounted in this region to stall. Again it was found that at lift coefficients above six-tenths the data showed no uniform trend. At lift coefficients below one-tenth, the curves under discussion are identical to those associated with stores mounted below the wing. Beyond this point, the drag due to the stores increases with lift coefficient. For the conditions involving the two outboard store positions however, ΔC_D due to the stores again begins to decrease with increasing lift when a C_L of approximately five-tenths is reached. This is probably caused by an end-plating effect of the pylons. It is also possible that the pylons may act as vortex generators which by energizing the flow would suppress separation over part of the wing and thus decrease the overall form drag.

It can also be seen from Fig. 18 that as far as the drag is concerned, the wing with stores mounted below is superior to the wing with stores mounted above. The difference in drags is the greatest at a lift coefficient of approximately five-tenths.

Another interesting result is that the interference plus store plus pylon drag is of the same order of magnitude as the wing alone at zero lift.

Pitching Moment.--Figs. 18 through 20 present the pitching moment curves for data simulating stores mounted on the bottom of the wing. No investigation was made of the pitching moments associated with the model when the stores were mounted on the wing upper surface. The pitching moment coefficients shown in these figures were measured about the quarter chord of the wing mean aerodynamic chord.

From Figs. 18 through 20 it can be seen that the effect of moving the store in the outboard direction is stabilizing. This is shown by the negative increase in the slope of the pitching moment curve as the store position progresses from 22 per cent to 60 per cent semi-span. The effect is small between the two inboard stations, however, at low lift coefficients. The effect of increasing store fineness ratio is also stabilizing. These effects are to be expected since both an outboard movement of the stores and an increase in their fineness ratio effectively move the composite model's center of pressure in a rearward direction. Fig. 21, which is a plot of dC_m/dC_L at quarter chord versus

with L/D as a parameter, illustrates the effects just described when the model is in the zero lift configuration. It should be mentioned that the wing with store mounted on the lower surface is less stable than the wing alone. The drag due to the stores produces a nose down pitching moment and would increase the static stability. For this reason it is felt that the interference effects of the stores produces the overall decrease in stability. These pitching moment results show good qualitative agreement with those found by Scallion, Ref. (2).

Reynolds Number Effect.--Figs. 22 through 25 are plots of the lift curves and drag polars for both the clean configuration and the wing with stores having a fineness ratio of 10 mounted on the top of the wing at the 22 per cent semi-span station. Both configurations have all curves plotted for effective Reynolds numbers of 3.97, 3.13, and 2.54 million. It can be seen from these figures that no appreciable Reynolds number effects exist in the range covered. Scallion found no Reynolds number effects except at lift coefficients above five-tenths where a slight increase in lift and decrease in drag at a Reynolds number of 2.77 was noted, Ref. (2). His model included a fuselage and had a different airfoil section from the one used in this investigation. This probably accounts for the slight difference in the two sets of data from a qualitative standpoint.

CHAPTER V

CONCLUSIONS

Based on the data obtained in this investigation the following conclusions have been drawn.

1. On the basis of lift, upper surface store mounting is slightly better than lower surface mounting. However, the drag data indicates that lower surface mounting is far superior.

2. With lower surface mounting, both lift and drag indicate that the stores should be mounted as close to the wing tip as possible. For upper surface mounting, however, though lift still indicates stores mounted near the tip are best, from the drag point of view the stores should be mounted as close to the fuselage as possible within the limits shown herein.

3. The effect of store fineness ratio on lift and drag is not critical when L/D is in the range of 8 to 12.

4. If more static stability is desired, stores of high fineness ratio should be mounted as close to the wing tip as possible. If less static stability is desired, just the opposite is true. Although these results were found with the stores mounted on the lower surface of the wing, they will probably be the same for stores mounted on the upper surface for the effects on the model's center of pressure should be similar.

5. A cambered pylon should probably be used when the stores are mounted on the upper surface of the wing near the tips in order to prevent stalling of the pylons due to spanwise flow.

CHAPTER VI

RECOMMENDATIONS

As previously mentioned, all the parameters affecting the low speed aerodynamic characteristics of the delta wing caused by external stores have not been investigated in this report. Factors which were omitted are:

1. Effect of pylon length
2. Effect of pylon chord
3. Effect of pylon sweep
4. Effect of pylon taper
5. Effect of pylon airfoil
6. Effect of store shape
7. Effect of wing thickness
8. Effect of wing aspect ratio
9. Effect of wing sweep
10. Effect of store, fuselage interference

In order to complete the work done in this report it is recommended that these parameters be studied.

APPENDIX

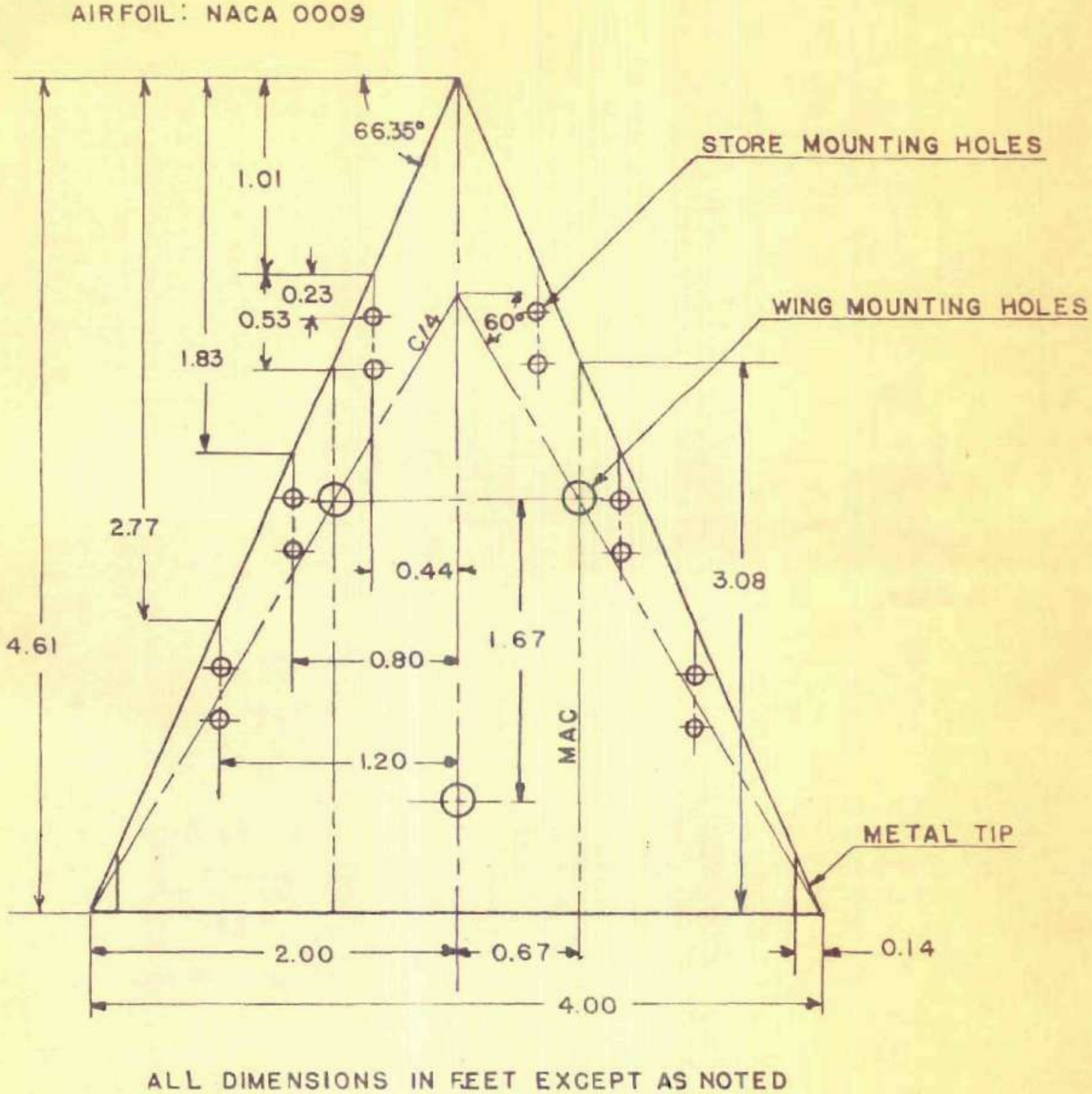
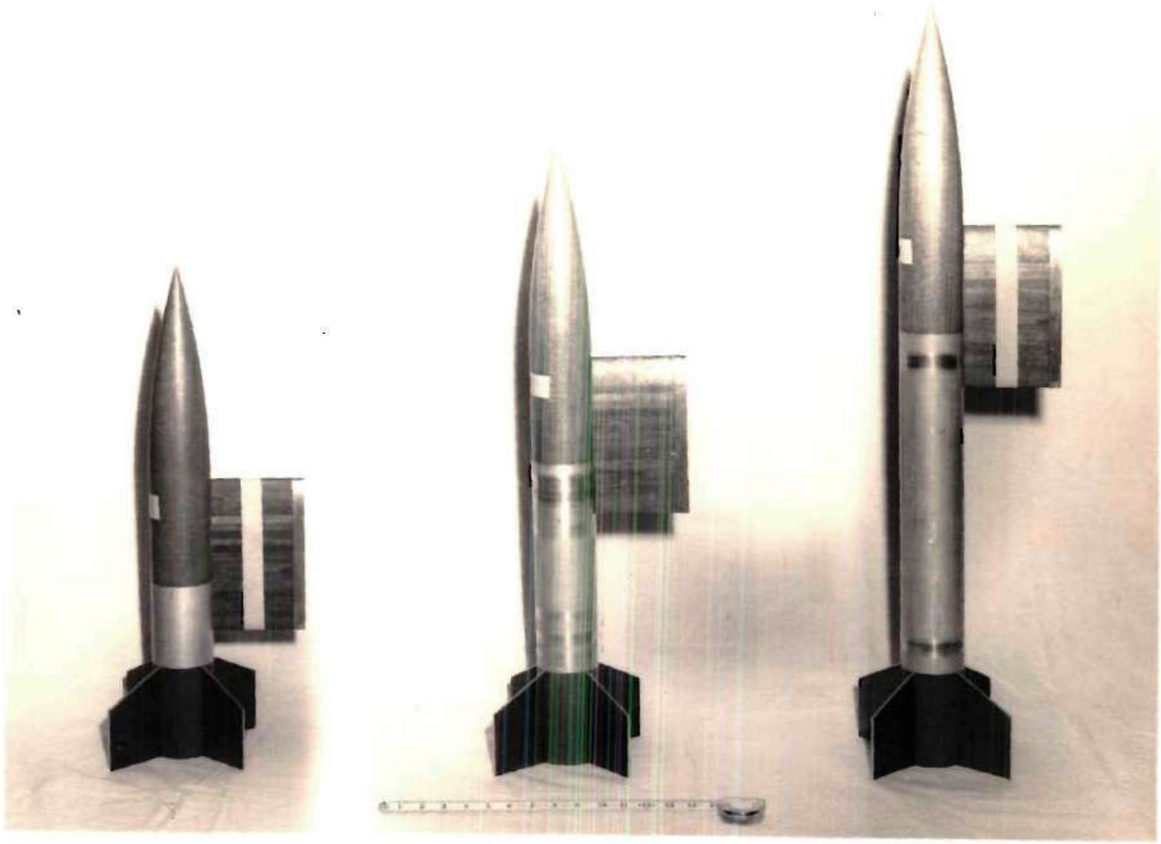


FIGURE 1

DIMENSIONS OF DELTA

SCALE: 1" = 1'



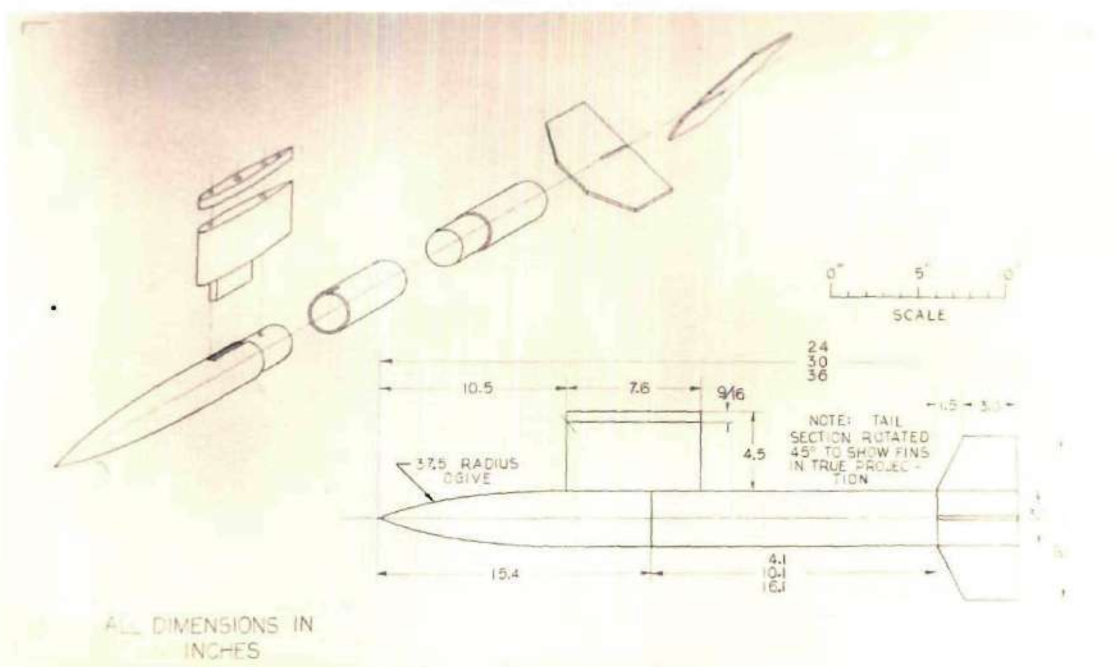


Fig. 2 External Stores

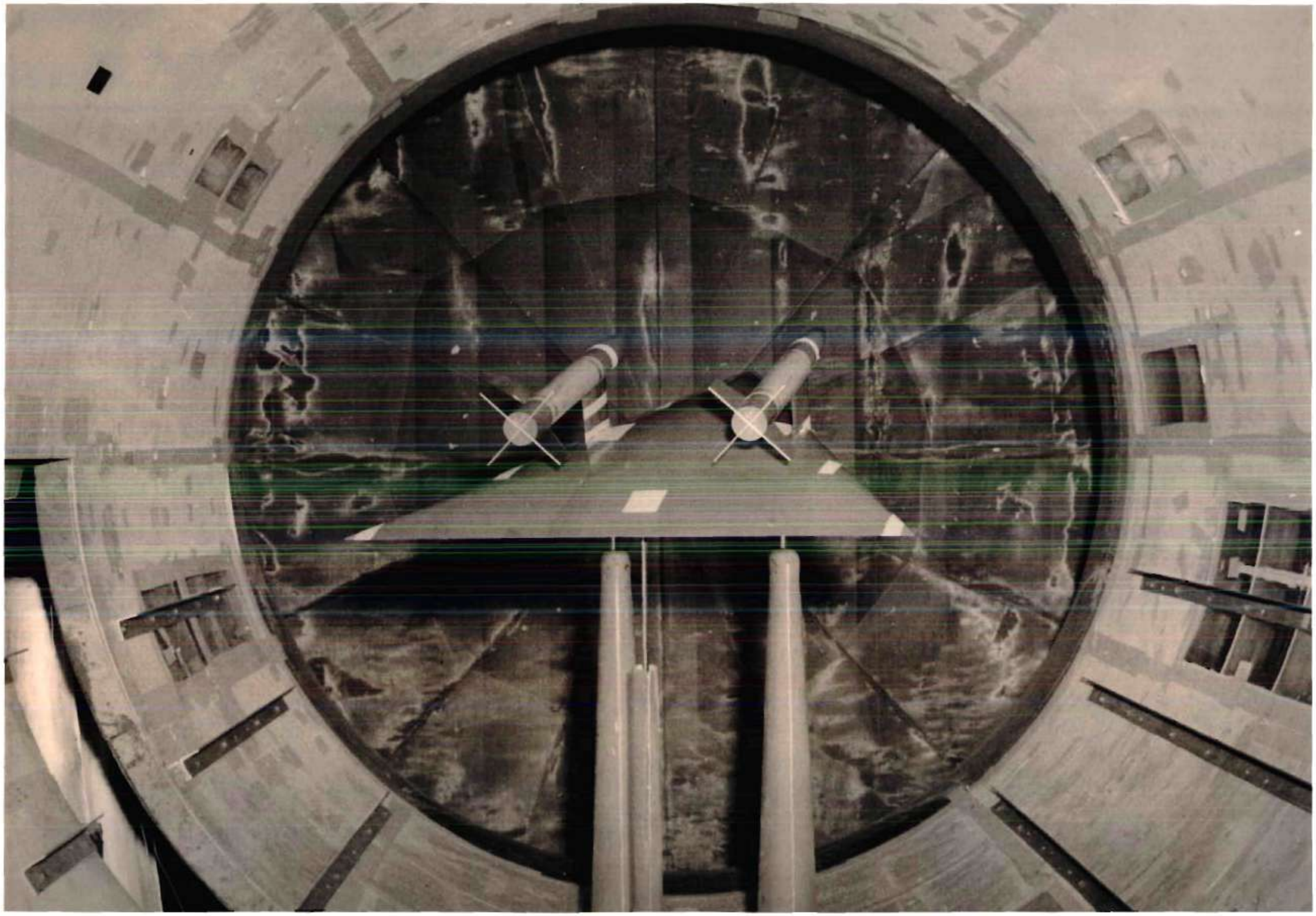


Fig. 3 Photograph of Model in Tunnel

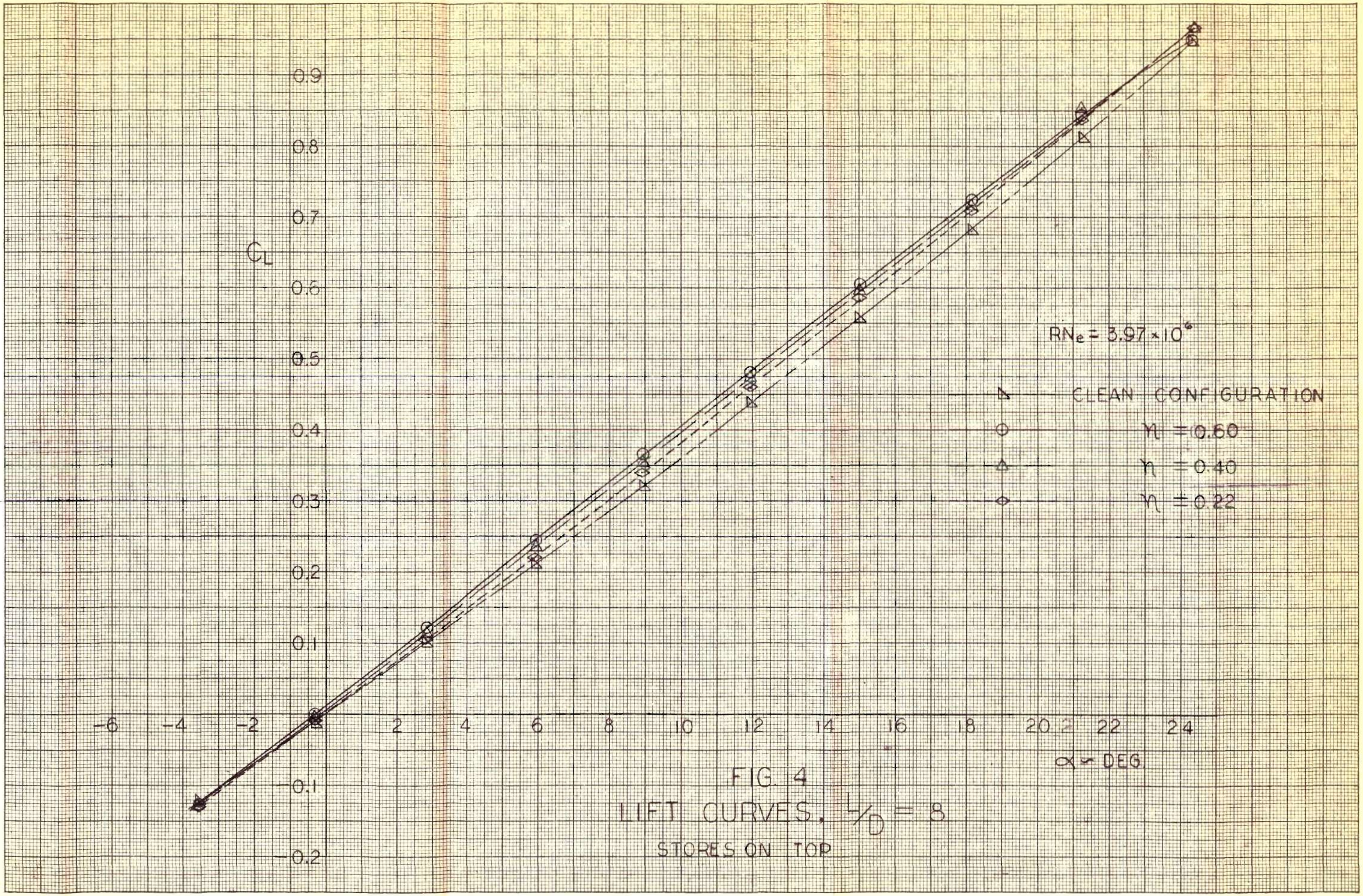


FIG. 4
LIFT CURVES, $L/D = 8$
STORES ON TOP

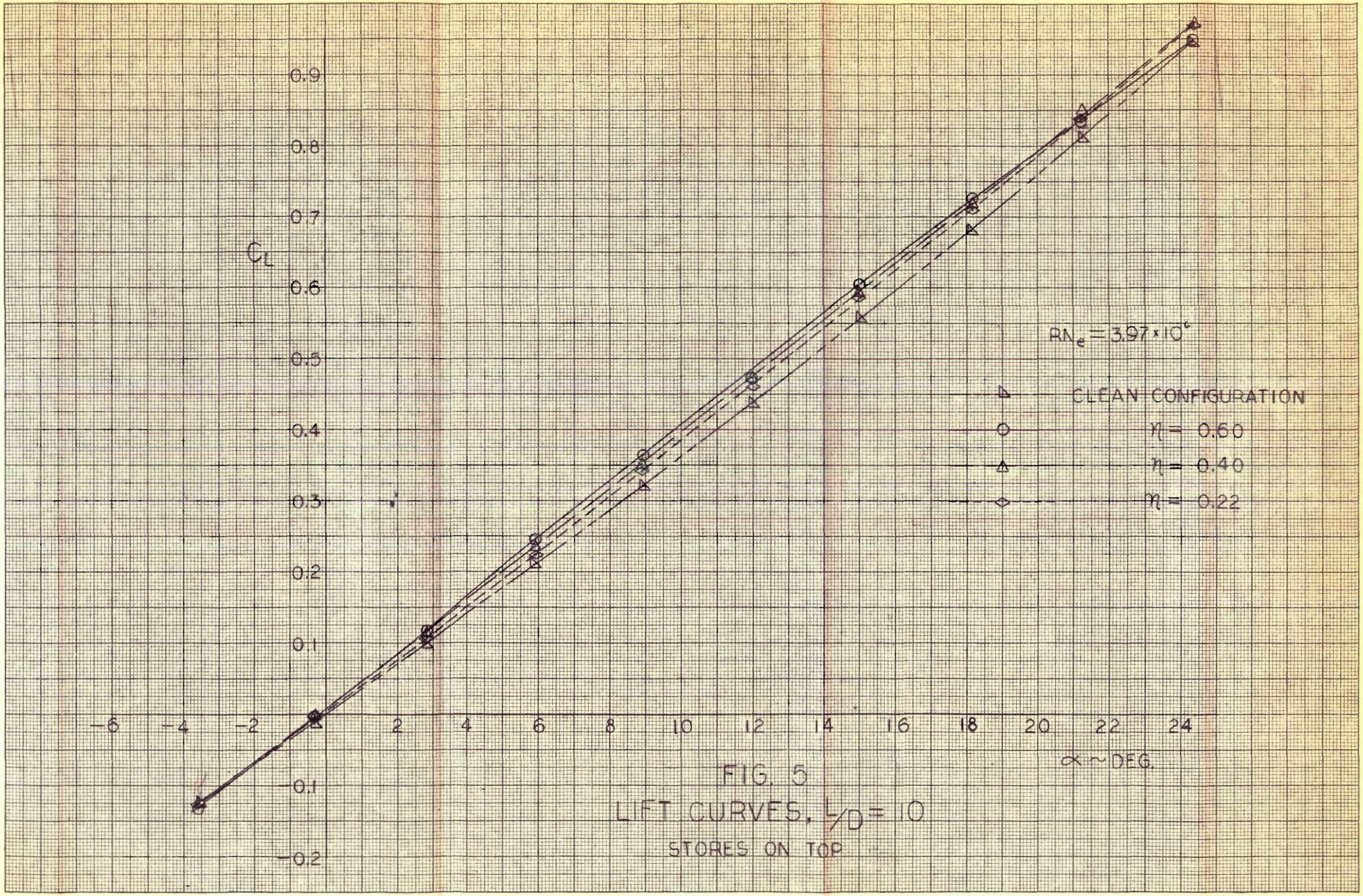


FIG. 5
LIFT CURVES, L/D = 10
STORES ON TOP

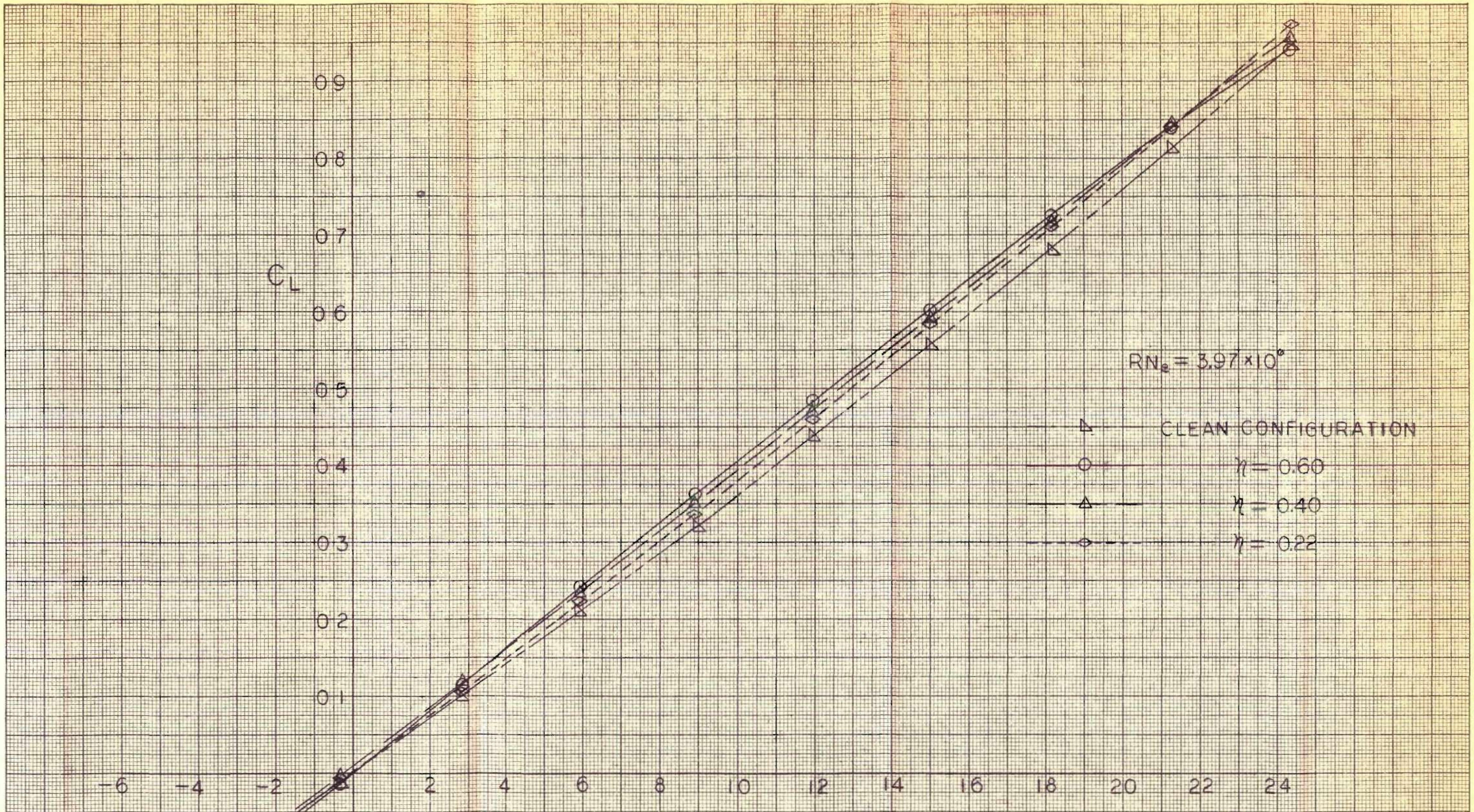


FIG. 6
LIFT CURVES, $L/D = 12$
STORES ON TOP

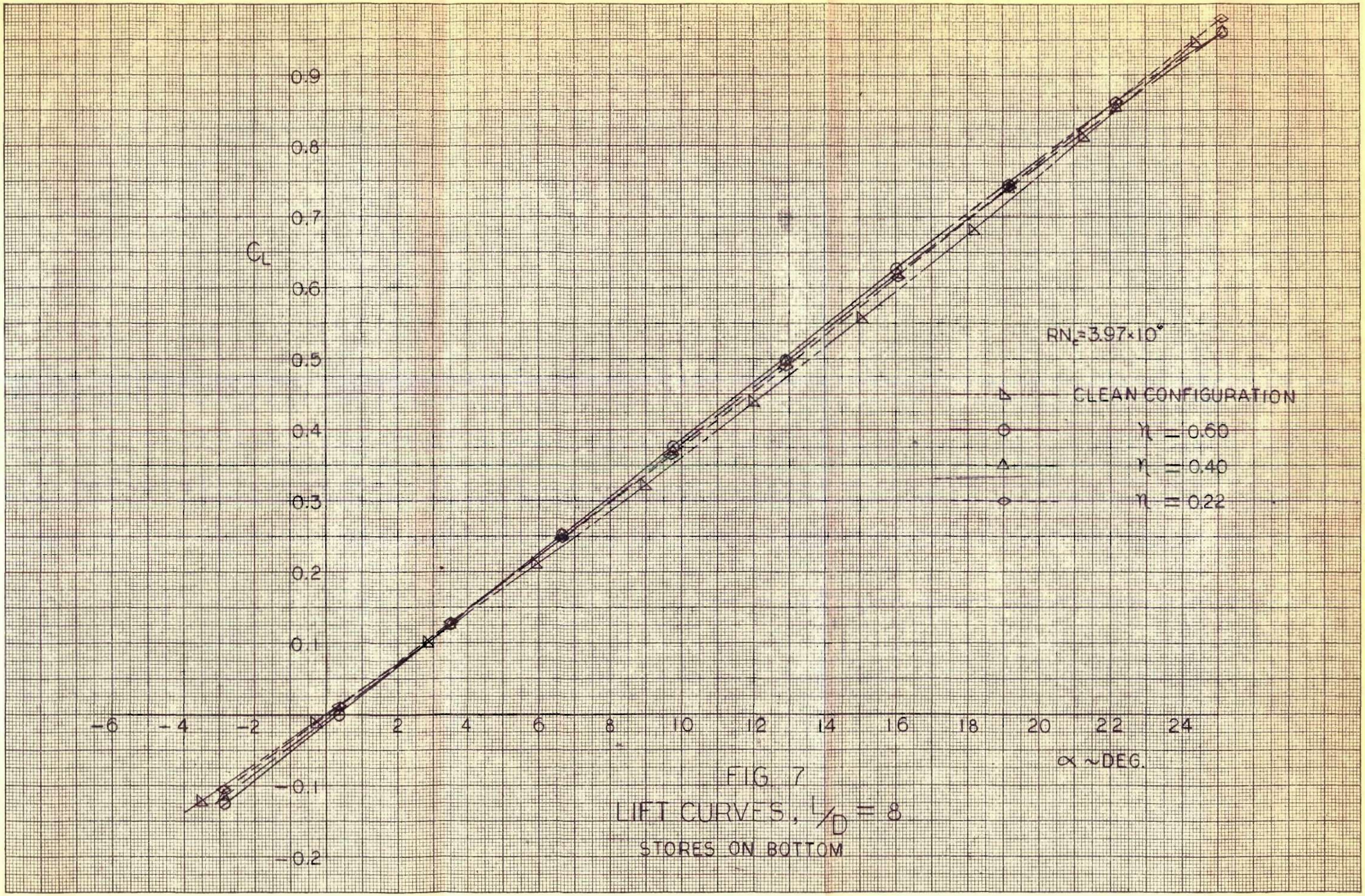


FIG. 7
LIFT CURVES, $L/D = 8$
STORES ON BOTTOM

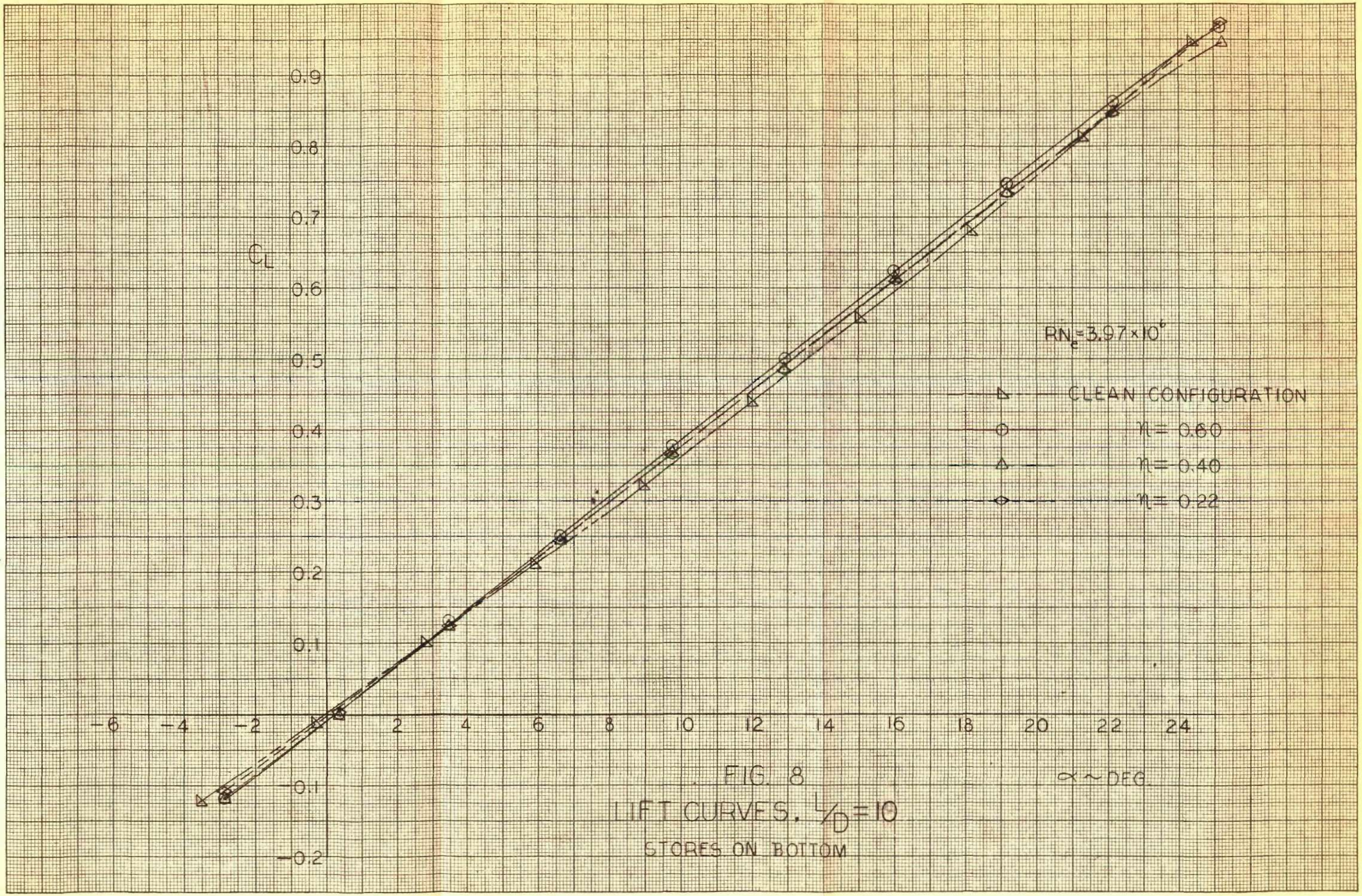


FIG. 8
LIFT CURVES, $L/D = 10$
STORES ON BOTTOM

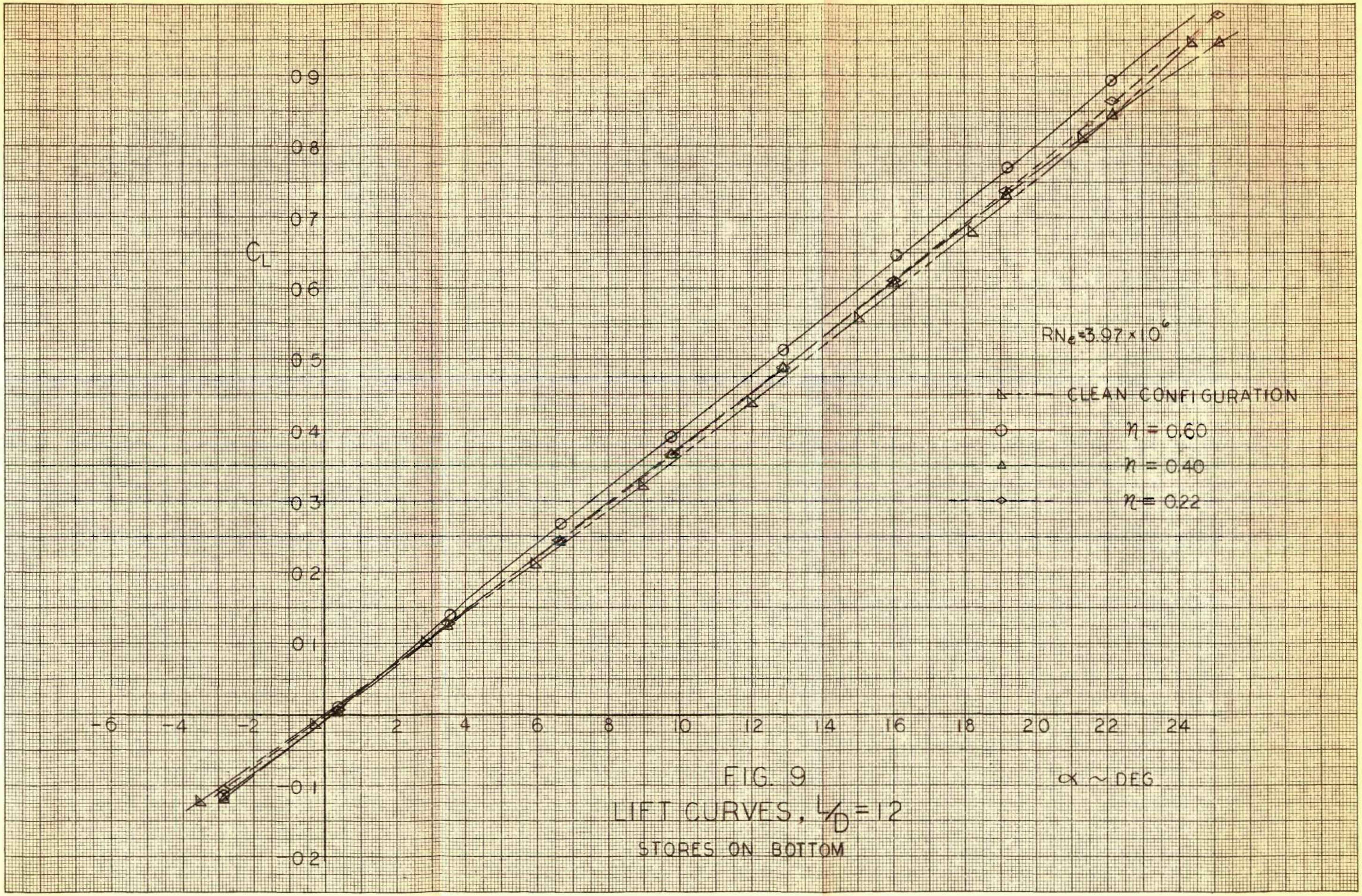


FIG. 9
LIFT CURVES, L/D = 12
STORES ON BOTTOM

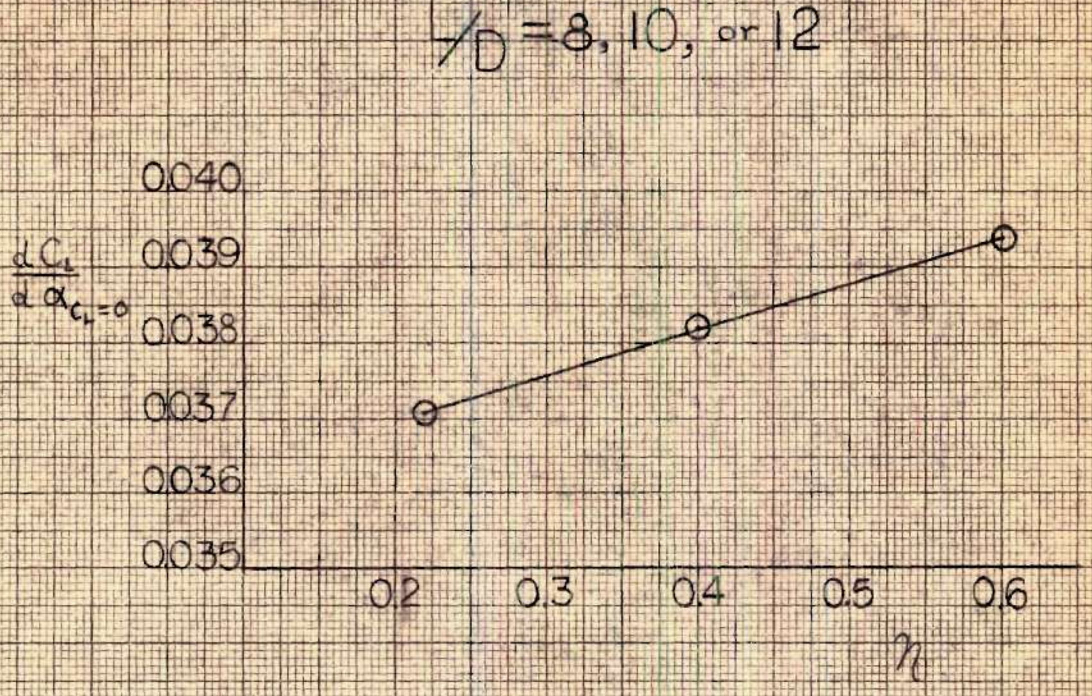


FIG. 10

VARIATION OF LIFT CURVE SLOPE WITH STORE SPANWISE POSITION

$C_L = 0$

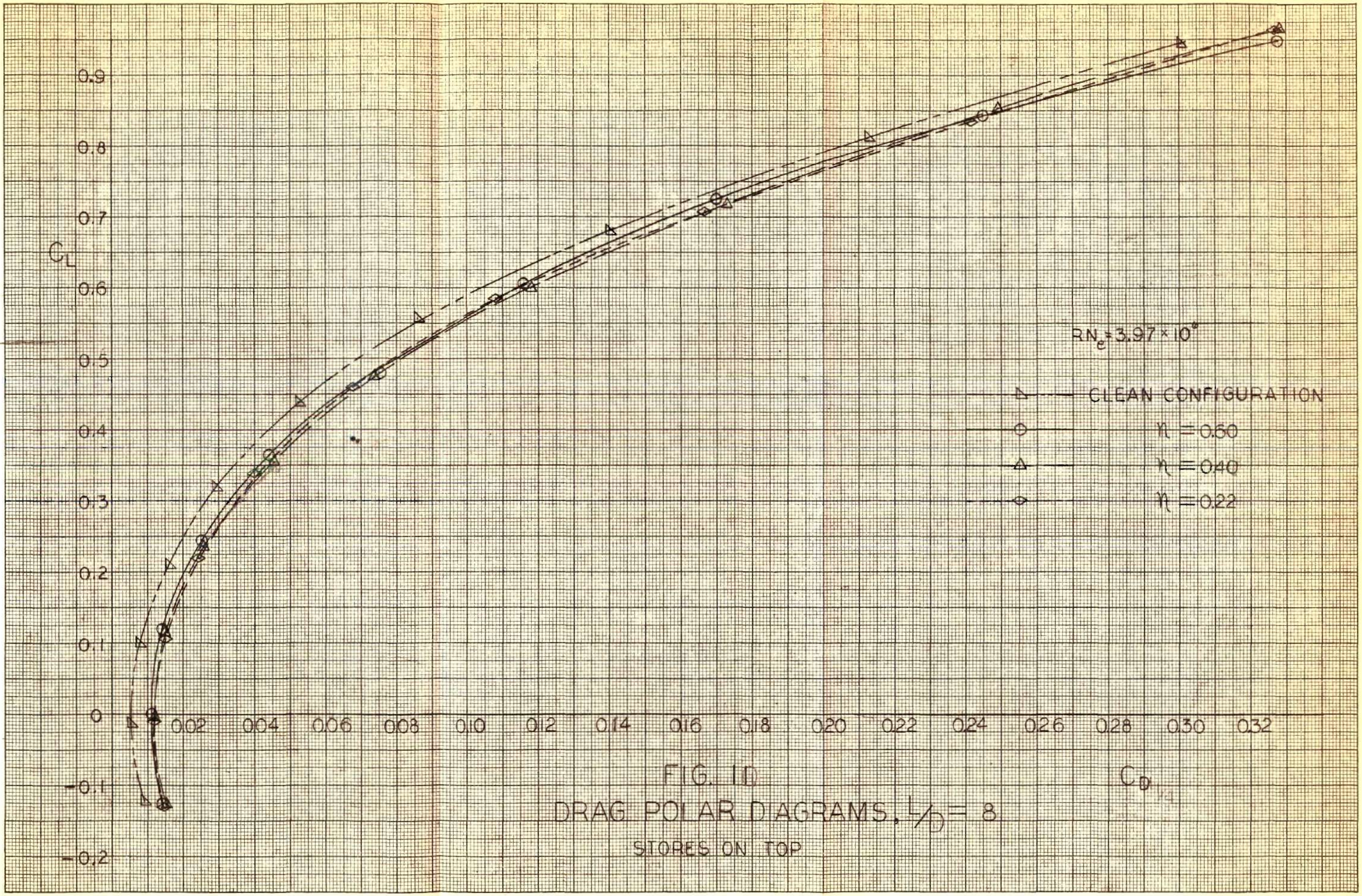


FIG. 10
DRAG POLAR DIAGRAMS, $L/D = 8$
STORES ON TOP

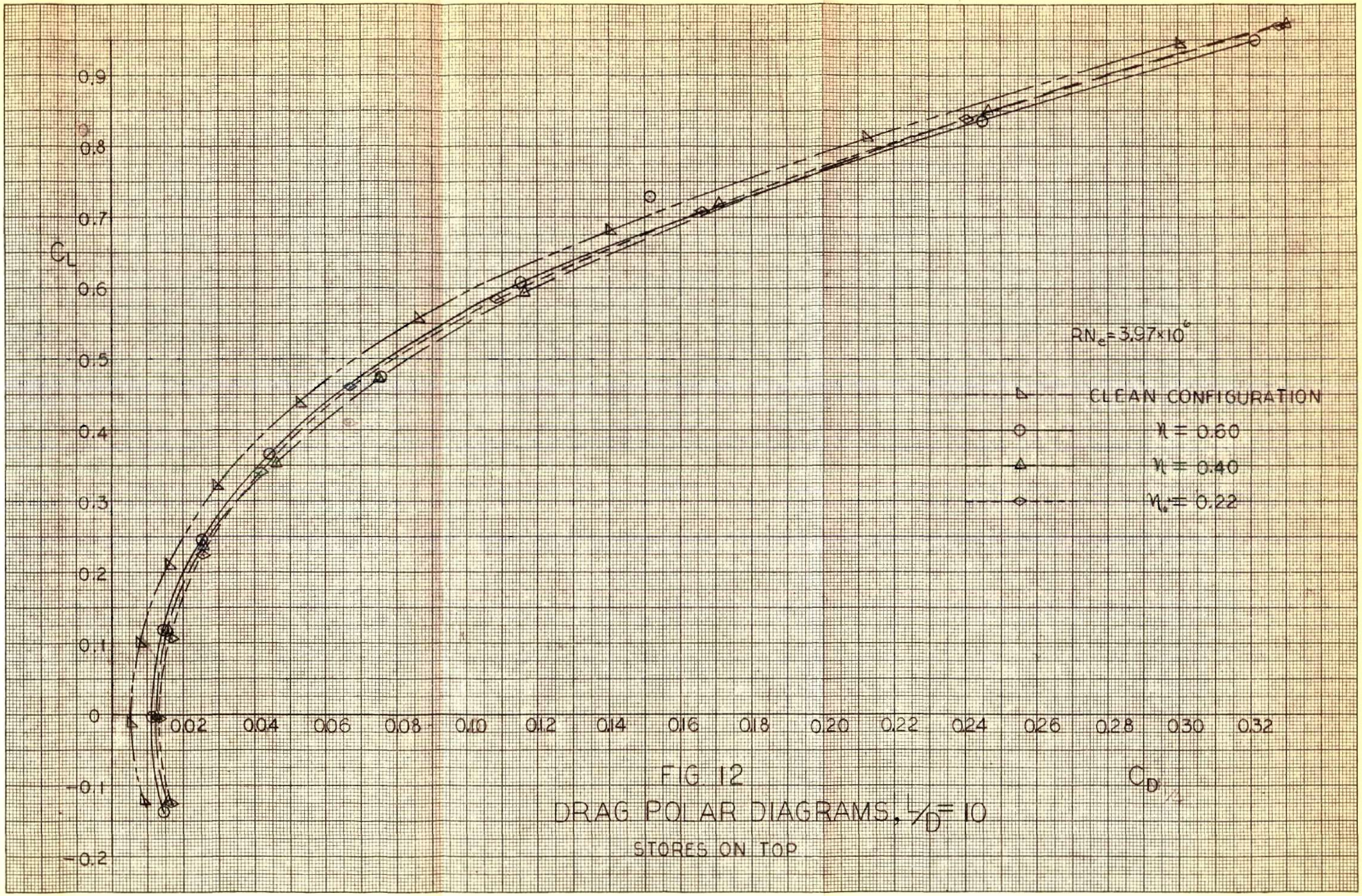


FIG. 12
DRAG POLAR DIAGRAMS, $L/D = 10$
STORES ON TOP

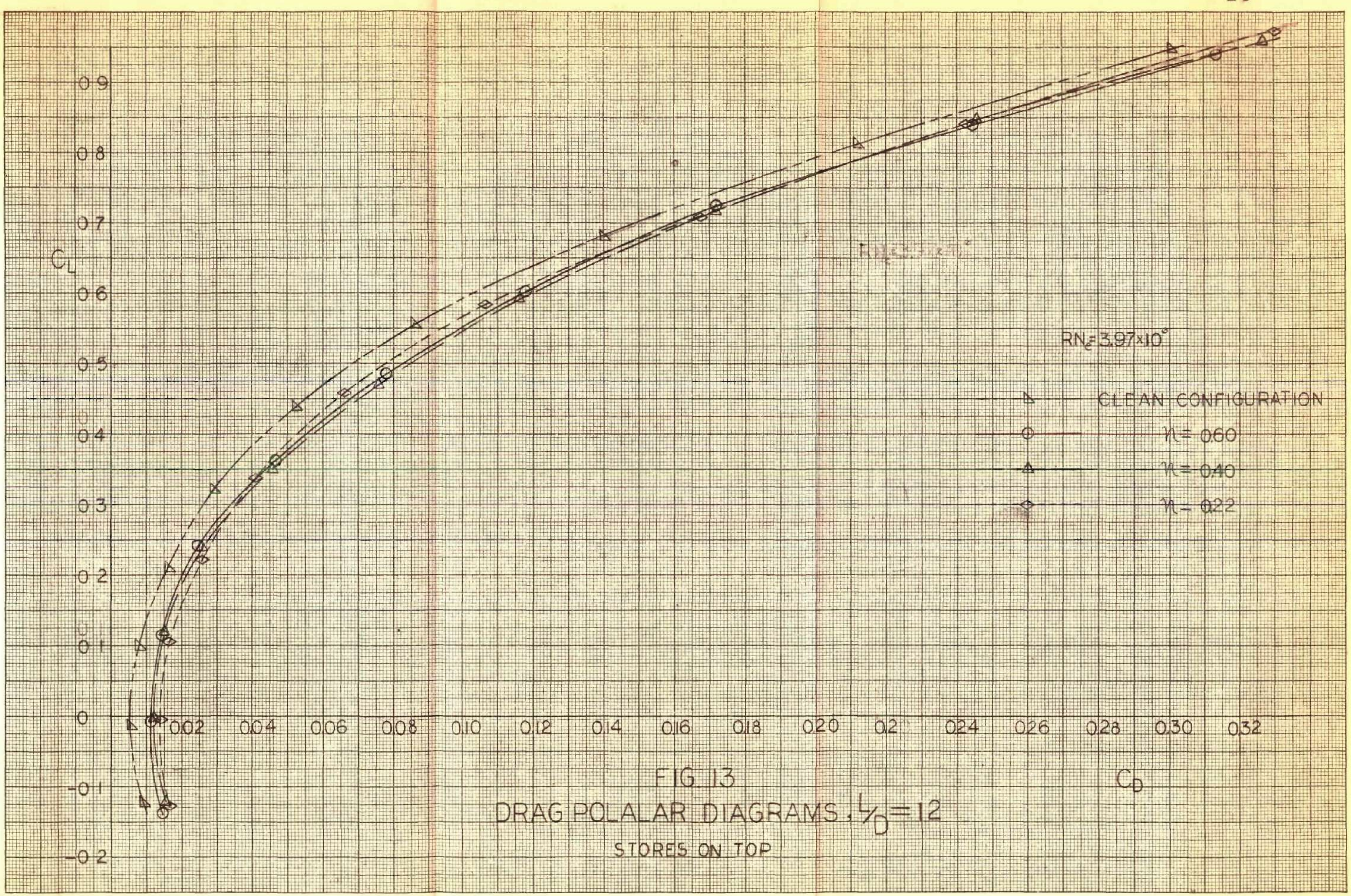


FIG 13
DRAG POLALAR DIAGRAMS, $L/D = 12$
STORES ON TOP

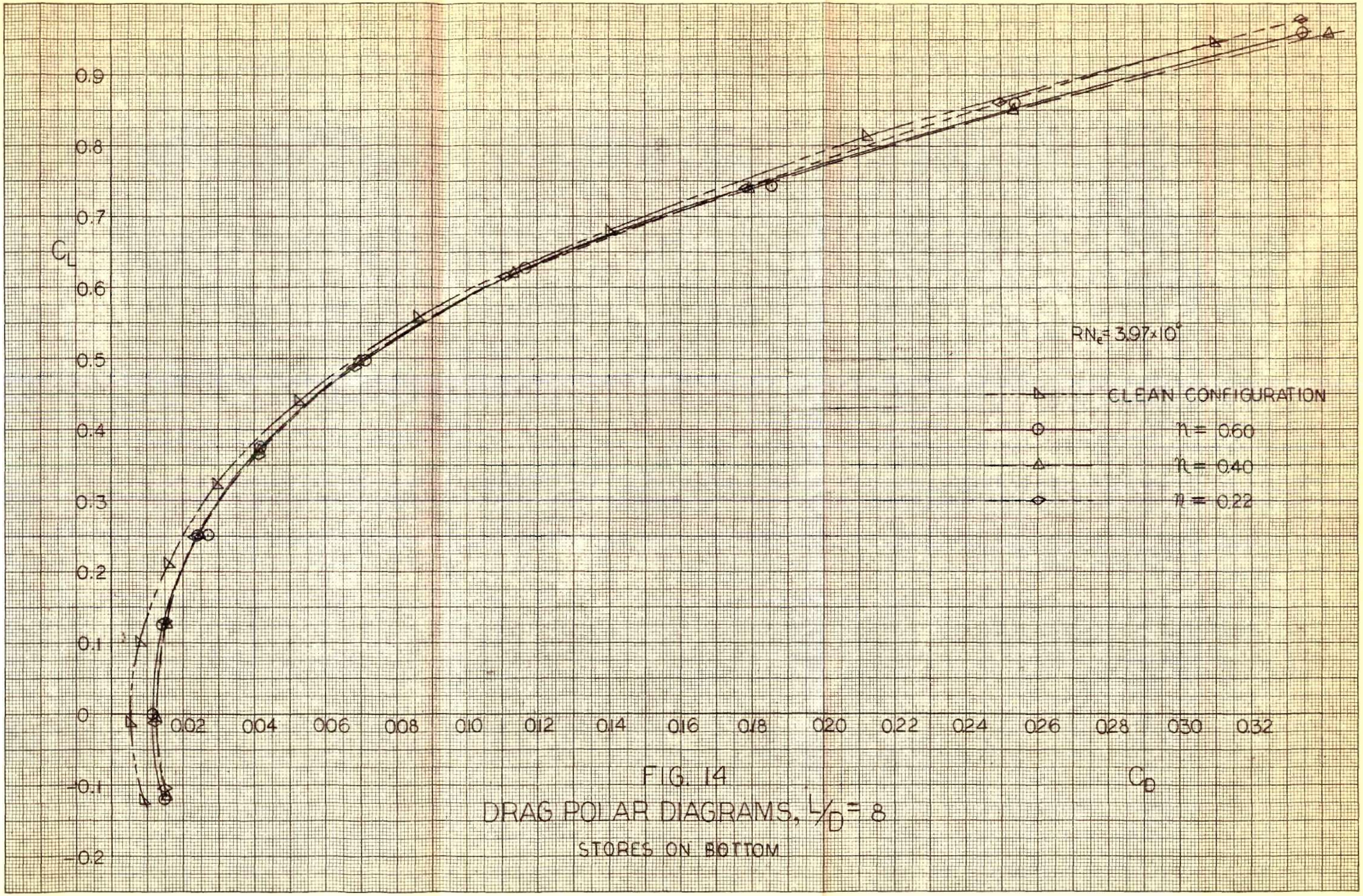


FIG. 14
DRAG POLAR DIAGRAMS, $L/D = 8$
STORES ON BOTTOM

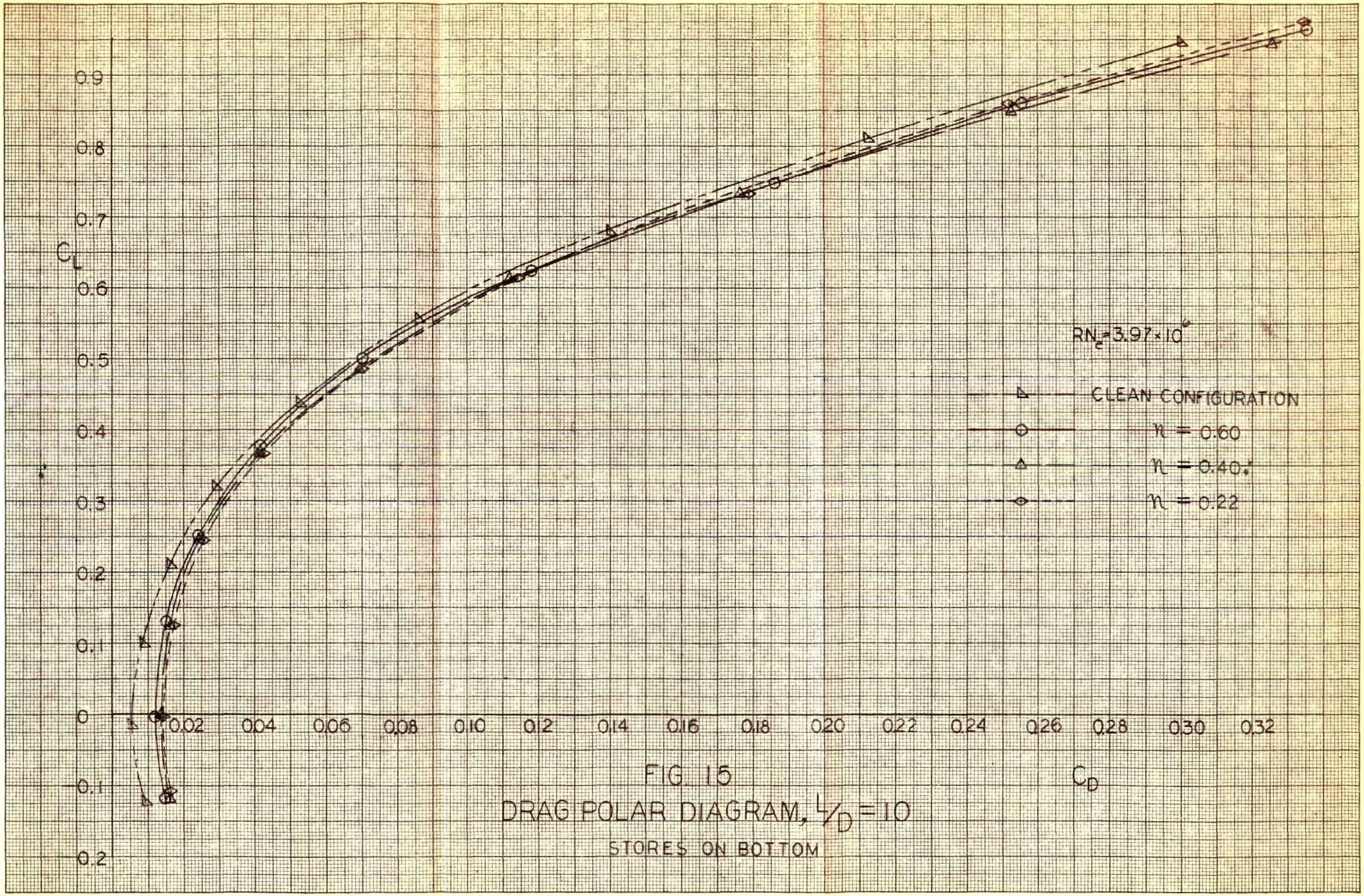


FIG. 15
DRAG POLAR DIAGRAM, $L/D = 10$
STORES ON BOTTOM

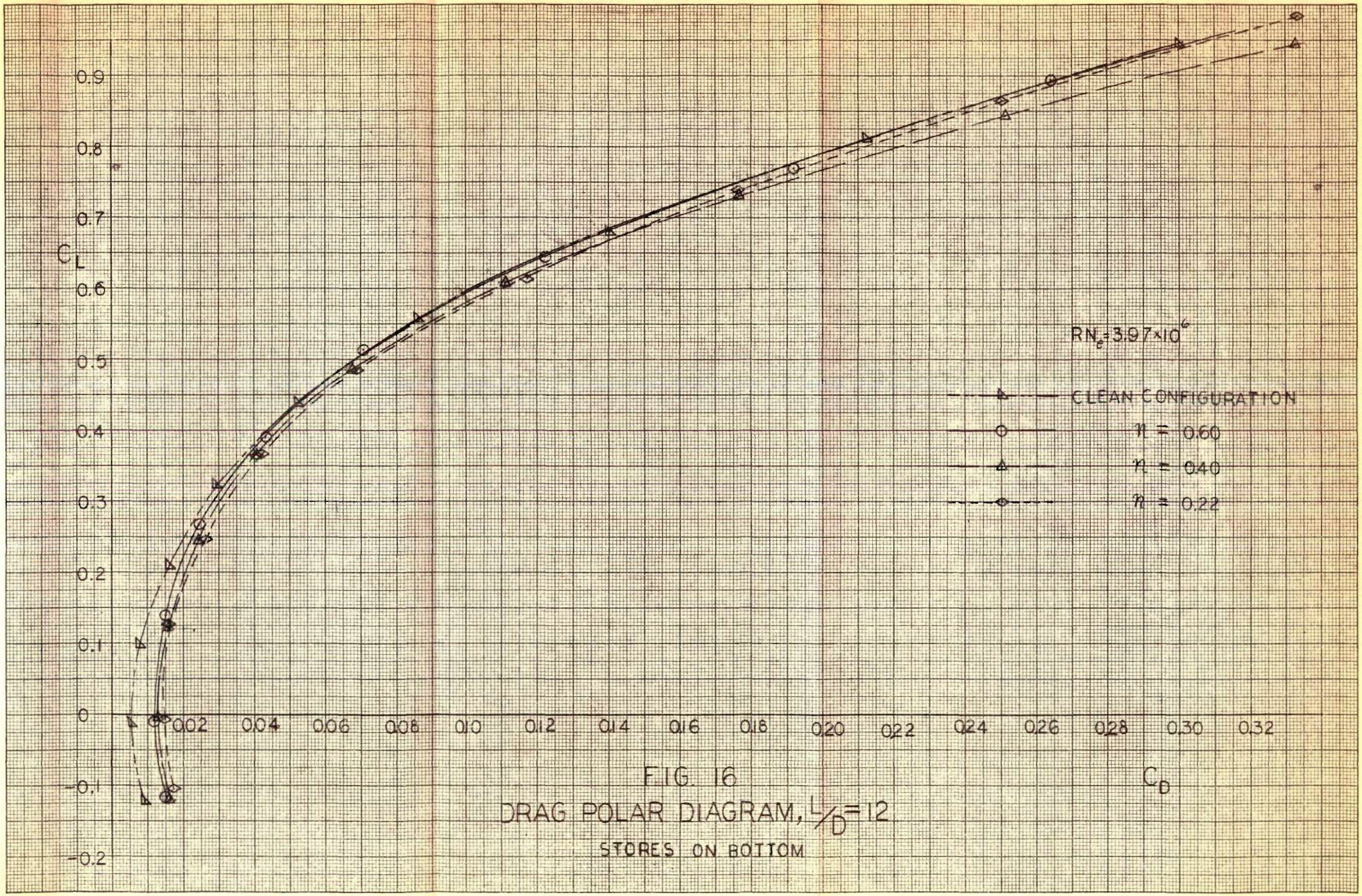


FIG. 16
DRAG POLAR DIAGRAM, $L/D = 12$
STORES ON BOTTOM

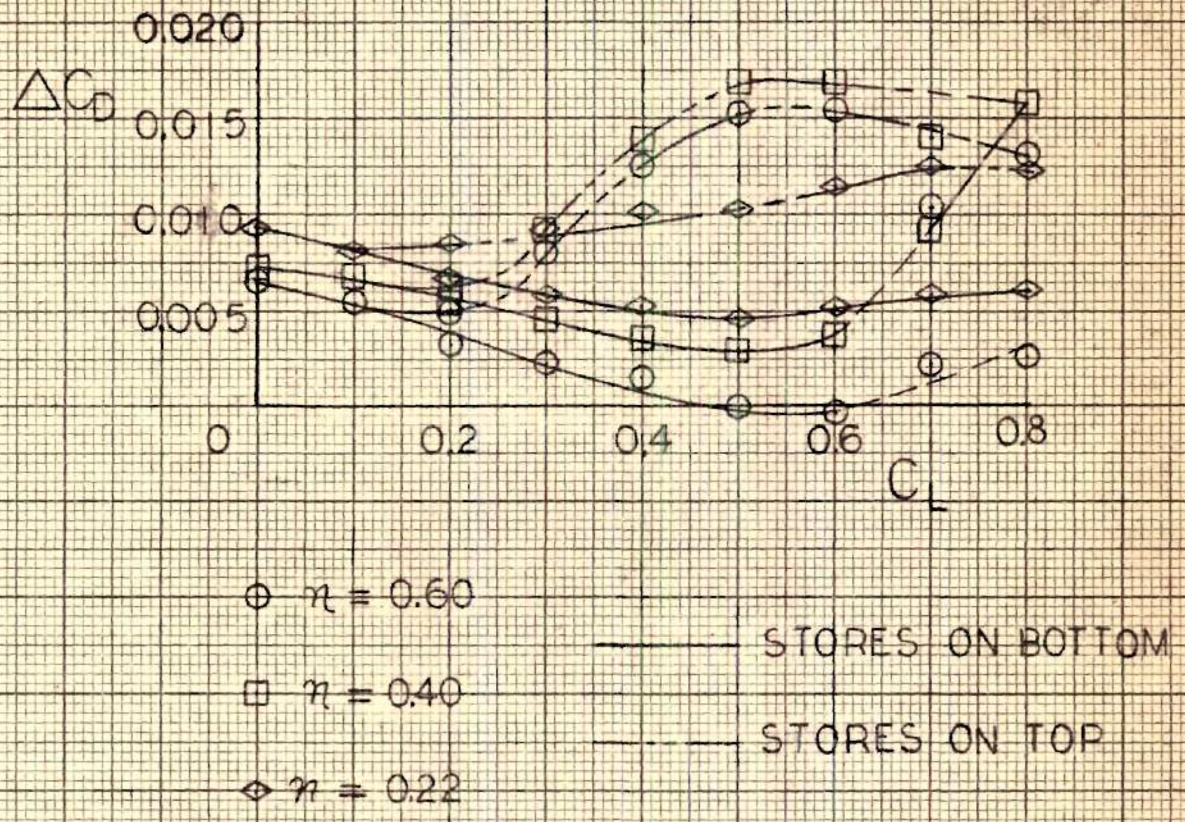


FIG. 17

INCREMENTAL VARIATION OF DRAG
WITH LIFT AND STORE SPANWISE POSITION
$L/D = 12$

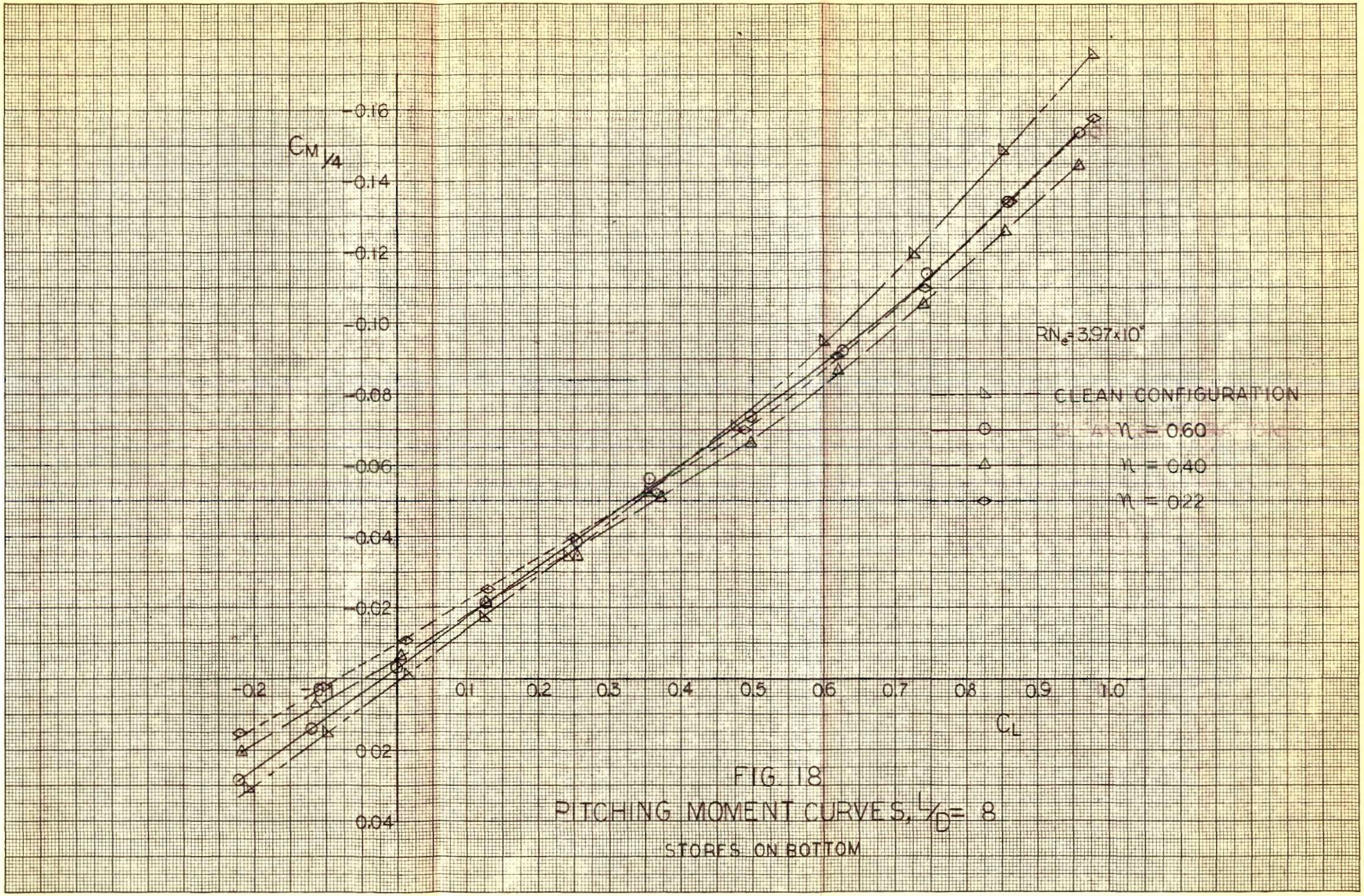


FIG. 18
PITCHING MOMENT CURVES, $L/D = 8$
STORES ON BOTTOM

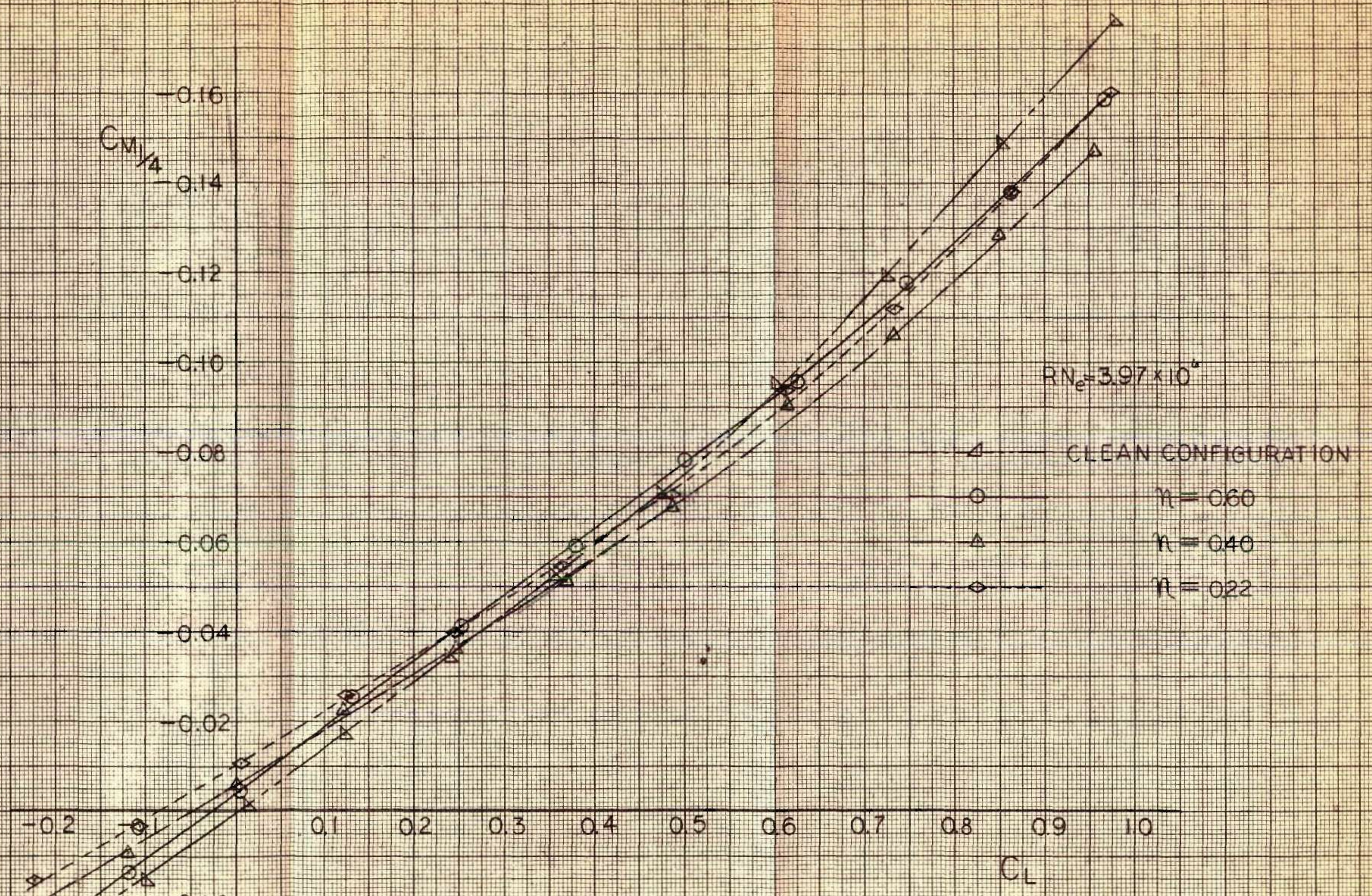


FIG. 19
PITCHING MOMENT CURVES, $L/D = 10$
STORES ON BOTTOM

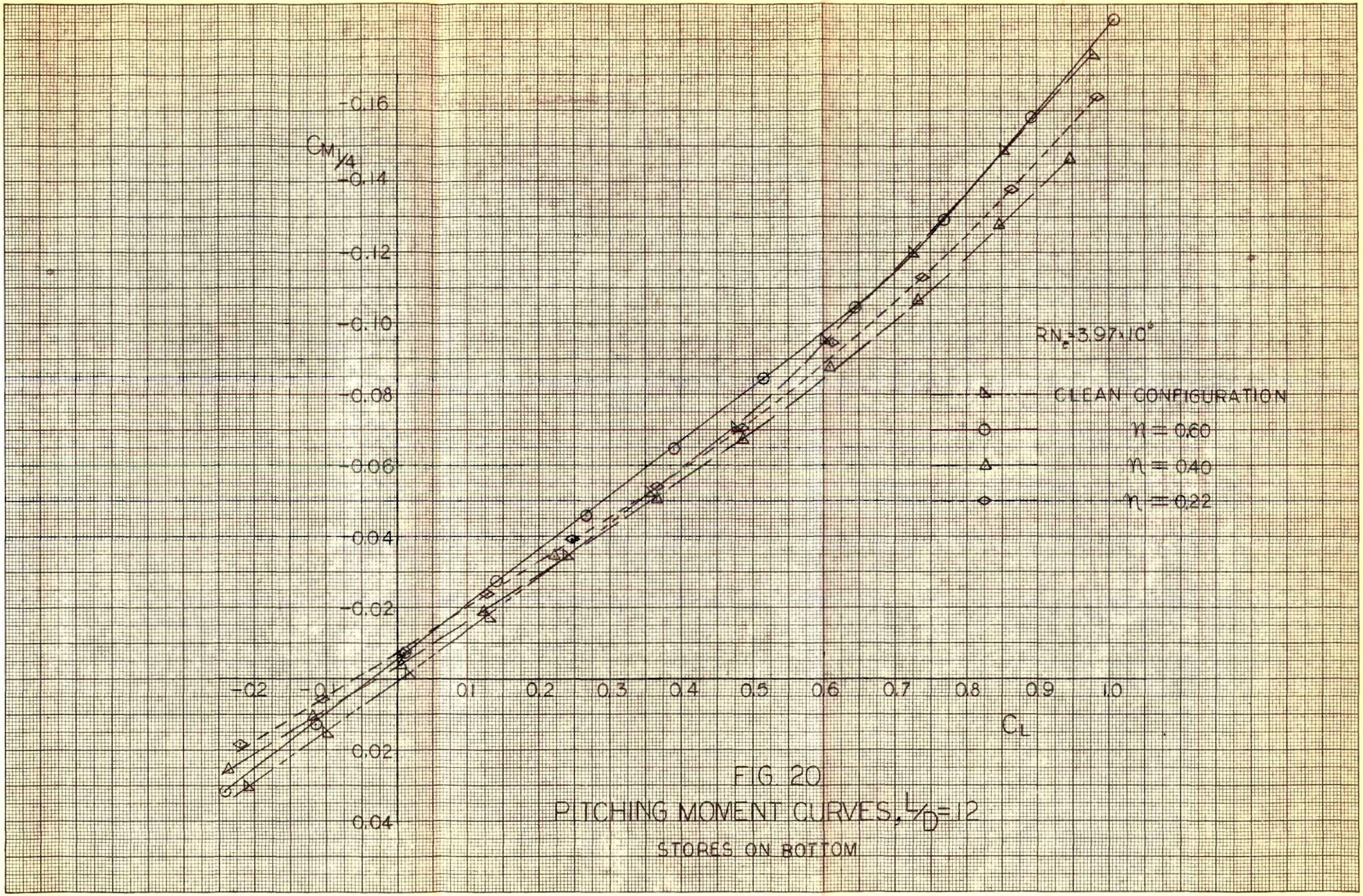


FIG. 20
PITCHING MOMENT CURVES, $L/D = 12$
STORES ON BOTTOM

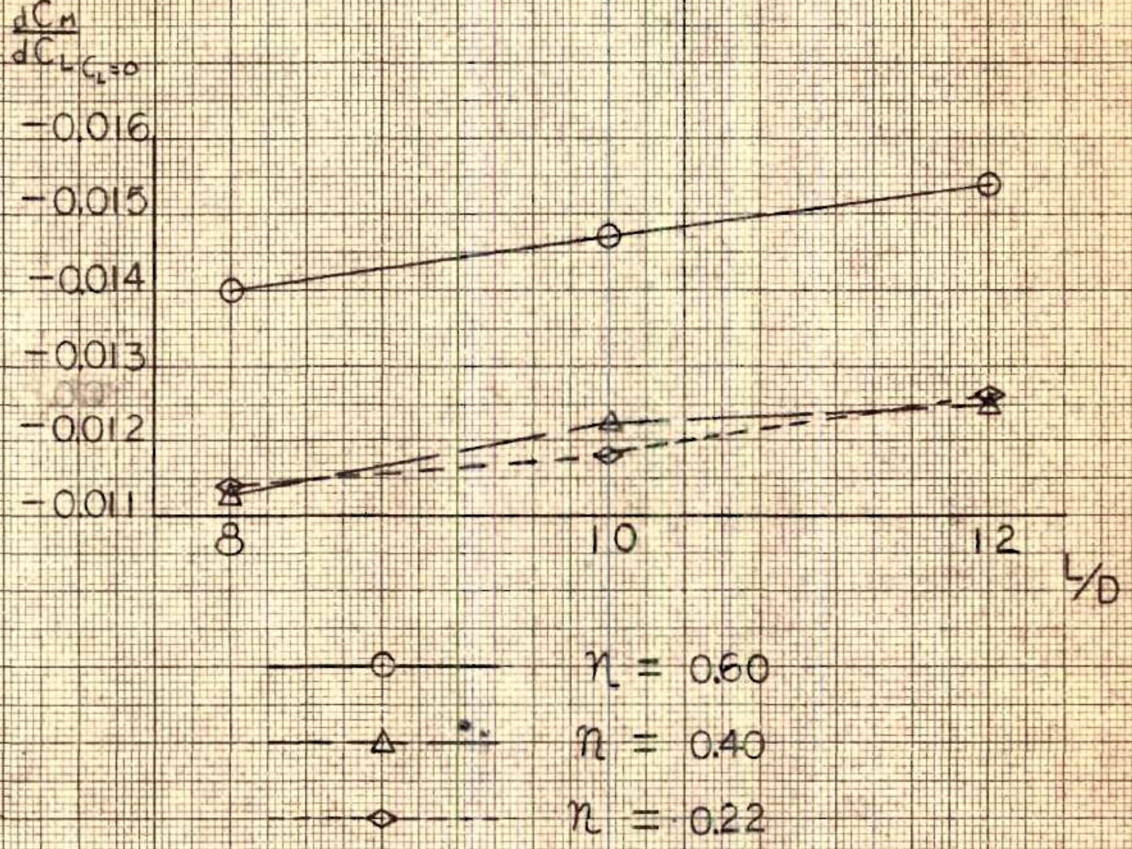


FIG. 21

VARIATION OF PITCHING MOMENT CURVE SLOPE WITH STORE FINENESS RATIO AND SPANWISE POSITION

$C_L = 0$

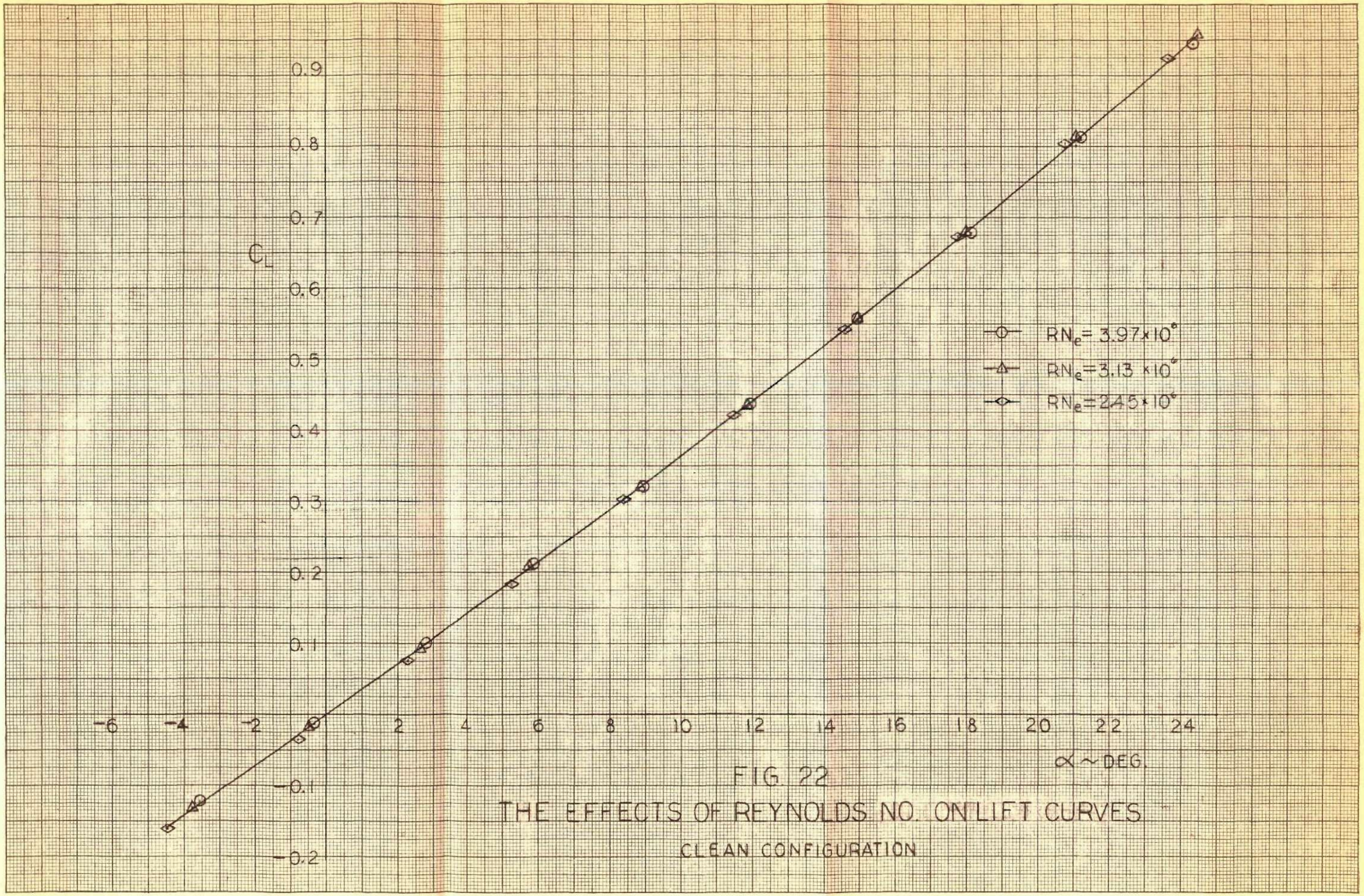


FIG. 22
THE EFFECTS OF REYNOLDS NO. ON LIFT CURVES
CLEAN CONFIGURATION

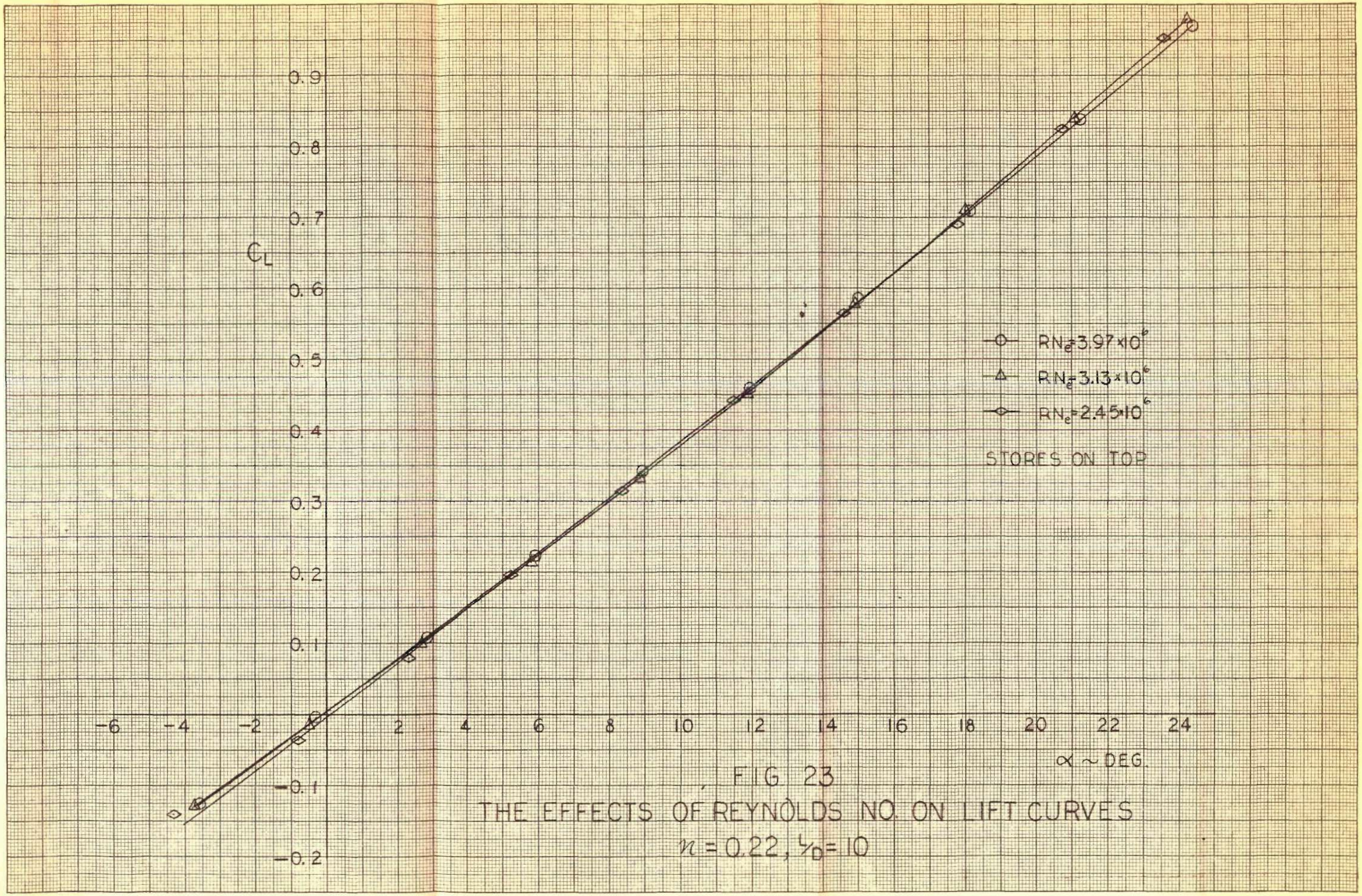


FIG. 23
THE EFFECTS OF REYNOLDS NO. ON LIFT CURVES
$n = 0.22$, $L/D = 10$

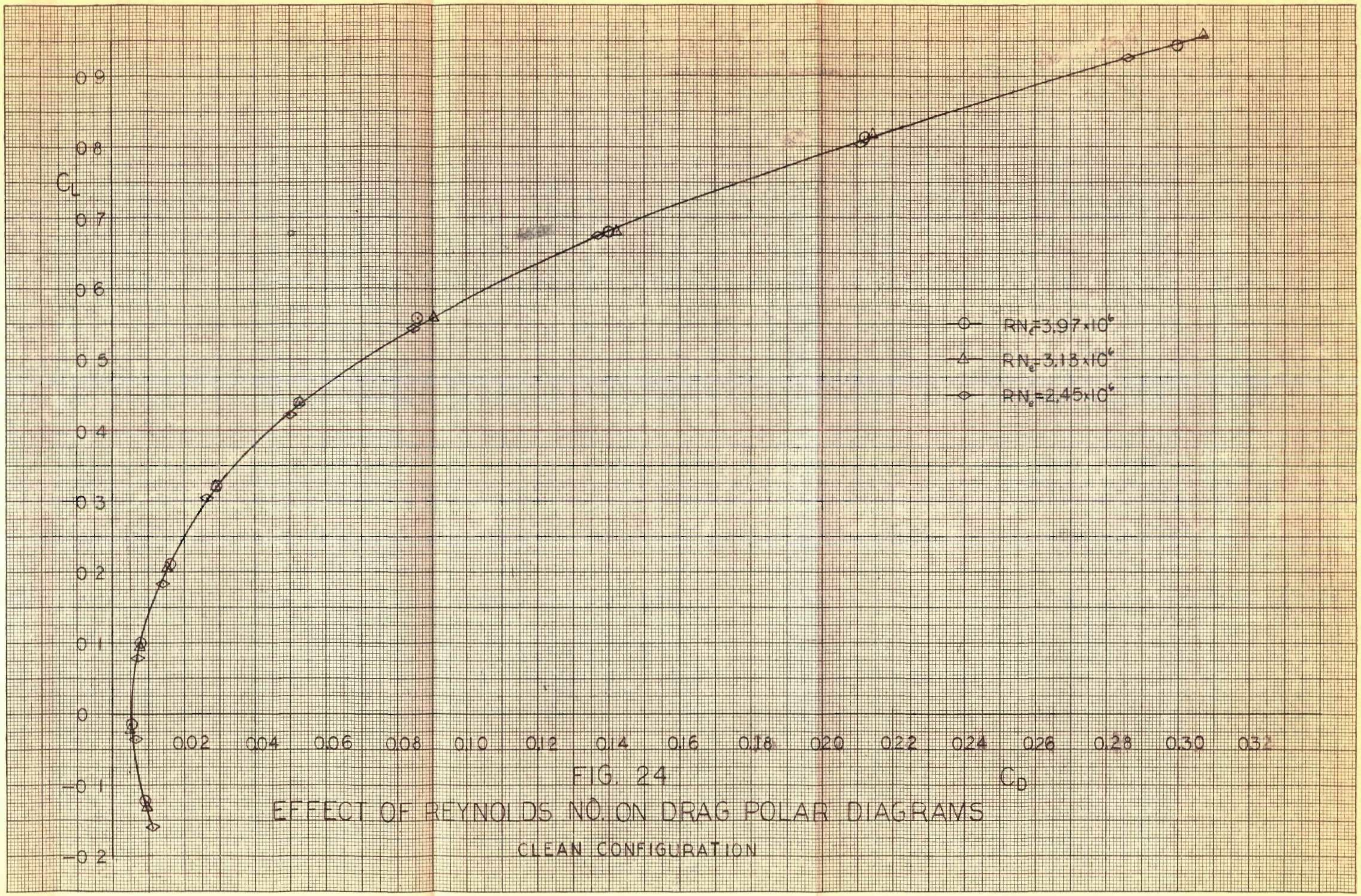


FIG. 24

EFFECT OF REYNOLDS NO. ON DRAG POLAR DIAGRAMS

CLEAN CONFIGURATION

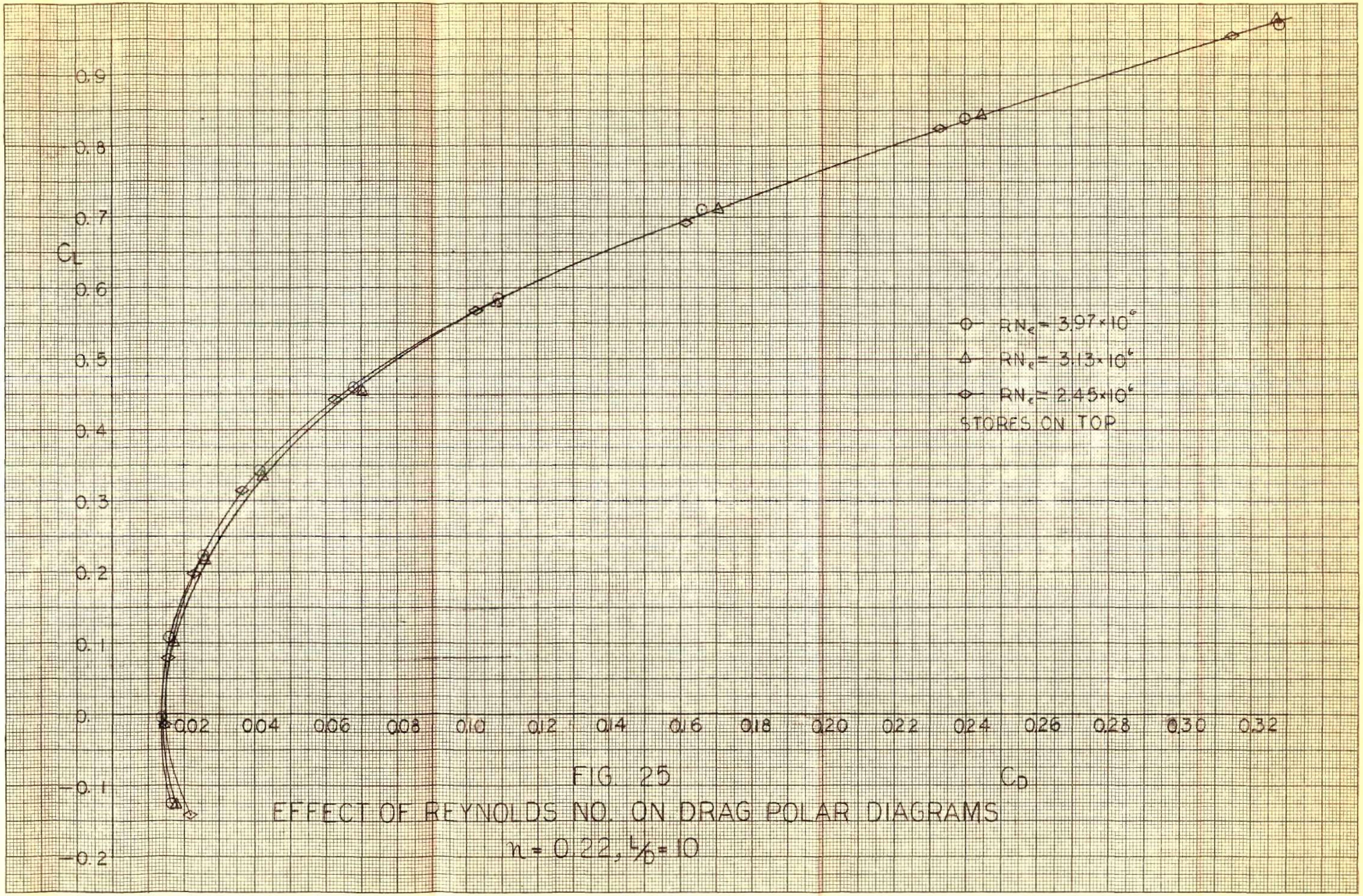


FIG. 25
EFFECT OF REYNOLDS NO. ON DRAG POLAR DIAGRAMS
$\eta = 0.22, L/D = 10$

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